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Analysis of offshore wind energy resources of China

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Abstract: With the economic development, the problems of energy shortage become increasingly severe. As offshore wind energy has advantages, namely it is clean, renewable, not accounting for land area, without noise pollution, with large reserves, etc., which gradually attracts people's attention. In this paper, China's offshore annual average wind field and monthly average wind field under the mean climate state conditions are obtained, and the corresponding wind density distribution is calculated. China's offshore wind energy reserves and distribution conditions through the analysis of wind energy density distribution are summarized, and finally some suggestions for coastal offshore wind energy development and utilization in China are put forward.

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Keywords: renewable energy, offshore wind energy, China offshore, wind speed, wind power density

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1 Introduction

Energy and environmental issues have become two major problems to the human survival and development, so searching new green renewable energy has become the important work of governments at present. Wind energy is abundant, widely distributed, with no greenhouse gas emissions, no pollution, et al. By 2008 electricity generated by wind was about 121GW all over the world, and the wind power supply capacity has exceeded 1% of the world consumption. The total installed capacity of wind power generator in our country by the end of 2008 was 12 210 bit MW, ranking fourth in the world [1].

However, there are a series of restrictions for the development of wind power farm on the land, such as the wind electric field covering large area, much noise pollution, and larger wind friction coefficients. Offshore wind energy utilization technology can overcome

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these difficulties of wind energy utilization on the land. The sea area is vast, and noise pollution problem won't exist. Besides, offshore wind energy is also relatively more abundant and stable, and the sea surface friction coefficient is small, which has incomparable advantages than that on the land. In Denmark, offshore wind energy farm was built firstly in 2002, and In Germany, its wind energy resource assessment has already been carried out and its wind farm site planning and design were completed [2]. The majority of population is concentrated in the eastern coastal areas in China, so the development of China's offshore wind energy has important strategic significance and practical significance [3].

In this paper, time and spatial distribution and changes of offshore wind energy in our adjacent sea areas are summarized based on the analysis of remote sensing retrieval data of 10 years (from 1999 to 2009) from QuickScat satellite. After the combination of sea wind distribution, human activities at sea and other features, the distribution ranges of marine wind power plant that our country can develop are analyzed, and some negative factors need to be considered during the construction process and some related recommendations are implied.

2 Data and method

2.1 Data

In this paper, satellite-derived data of sea surface wind speed is QuickScat monthly mean data provided by American Remote Sensing Systems Research (Remote Sensing System, RSS), downloaded from http://www.ssmi.com/qscat/qscat_description.html. Data spatial resolution is 0.25°×0.25°. This data set improves the accuracy of microwave scatterometer by using microwave radiometer, while four satellite microwave radiometers (F13 SSMI、F14 SSMI、F15 SSMI and TMI) are used to determine the scope of the rain, and the quality control is carried out on the sea wind speed data retrieved from QuikScat . Data used in this paper are average sea surface wind speed retrieval data, and time span is a total of 10 years from July 1999 to June 2009. The research scope covers China's adjacent sea areas, including the Bohai Sea, the Yellow Sea, the East China Sea and part of the South China Sea.

2.2 Data processing method

Calculation of wind power density is as the following. Wind power is extracted from air flow using wind turbines or sails to produce mechanical or electrical power that human can use.

If the air mass is m and velocity is v, then its kinetic energy is:

$$E = \frac{1}{2}mv^2 \tag{1}$$

so, the kinetic energy of unit volume air is:

$$E = \frac{1}{2}\rho v^2 \tag{2}$$

where ρ is the air density.

However, it is not enough only to know the wind energy of unit volume air. The most important indicator to wind energy evaluation is the energy density of wind energy flow, i.e., due to the flow of air, energy through unit cross-section per unit time should be proportional to the wind speed, which is the wind energy flowing vertically through unit cross-sectional area per unit time, namely wind power. So the wind power density formula is as follows

$$W = \frac{1}{2}\rho v^3 \tag{3}$$

At normal atmospheric pressure and at 20 °C temperature, air density ρ is approximately 1.2 kg/m^3, and this value will be used in the following calculation. The average wind power density (3) over a period of time T should be as the following formula.

$$\overline{W} = \frac{1}{T}\int_0^T \frac{1}{2}\rho v^3 dt \tag{4}$$

3 Offshore wind speed distribu tion analysis

3.1 The average spatial distribution characteristics of offshore wind speed in China's adjacent sea area for many years

Annual mean wind speed of climate mean state in China's adjacent sea area shows that the average wind speed of the East China Sea and the South China Sea is greater than that of the Yellow Sea and the Bohai Sea (see Fig. 1), and offshore wind speed is greater than the nearshore wind speed, which is due to the longer sea-based wind zones compared with land-based wind zones, and the friction coefficient is small. As the Taiwan Strait has pipeline effect and local characteristics of the land sea distribution, it shows large wind speed in China's adjacent sea area with multi-year mean wind speed of 10 m/s or so. Wind speed is also large in the spindle sea area of Kuroshio, Luzon Strait and Tsushima Strait, with multi-year average wind speed greater than 8 m/s. Annual mean wind speed in

the Yellow Sea and the Bohai Sea coast is about 6 m/s, while the annual mean wind speed in the East China Sea and the South China Sea coast is greater than 7.5 m/s. The mean wind speed in the Liaodong Bay at the northern of the Bohai Sea is 6.7 m/s or so, which is the large wind speed sea area in the Bohai Sea. Multi-year mean wind speed of Zhoushan sea area of the Yangtze River estuary is much greater than that of offshore sea area, about 8 m/s or so.

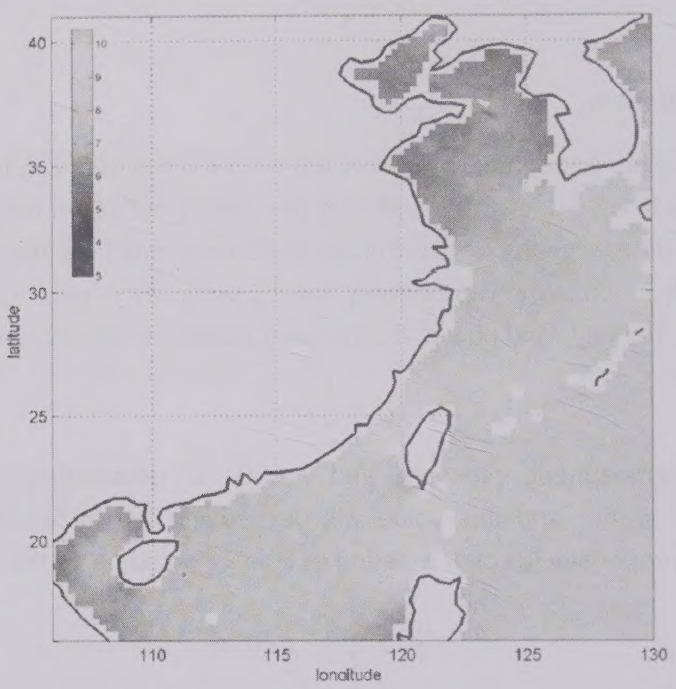

Fig. 1 Annual mean wind speed distribution map of climate mean state in China's adjacent sea area (m/s)

3.2 Seasonal variation analysis of sea wind speed in China's adjacent sea areas

Climate state wind speed distribution of each month in China's adjacent sea area is calculated through the average QuikScat satellite data of 10 years, which implies that wind seasonal variation is significant in China's coastal areas. Overall, wind speed is much larger in winter and smaller in summer. In winter, all coastal regions of China are affected by cold air, and the prevailing wind is the northerly wind, with gales occurring more frequently with long duration and greater wind speed. In spring, although cyclones, anticyclones and frontal activity are more frequent and the wind speed is also large, however because of the unstable wind direction, the duration of gale is short. In summer, the region is dominated by subtropical high and India low pressure, and the prevailing is southerly winds. In this season, wind force is relatively smaller besides typhoon. In spring,

wind direction in autumn is unstable, and because it is affected both by typhoon and cold winds, the monthly mean wind speed is greater. Among which, wind speed value in December is maximum, and then it decreases to a minimum value in May, and after May wind speed begins to increase gradually. The maximum wind speed for each month distributes in the vicinity of the Taiwan Strait basically, among which, the maximum wind speed in Taiwan Strait is up to 14 m/s in December, while the maximum wind speed in the Taiwan Strait in May is only 8m/s or so. In addition, sea surface wind speed is also greater in the spindle of Kuroshio flow area.

Monthly analysis of climate-state wind speed distribution shows that wind speed in October in the Bohai Sea is greater than that in most areas of the Yellow Sea, and the maximum wind speed is 8.5 m/s, with the average wind speed of 7.5 m/s. From November to December, winds enhance further in southern Bohai Sea. From the beginning of January, wind speed in the Bohai Sea begins to weaken, and in March, the average wind speed in the Bohai Sea is less than average wind speed in the Yellow Sea, and it reaches the minimum value in May. The maximum wind speed of the Bohai Sea mostly distributes in the Liaodong Bay which is in the northern part of the Bohai Sea, where the maximum average wind speed in November is up to 9m/s or so. The minimum average wind speed is only 4 m/s or so, which happens in June. The maximum value of average wind speed in the Bohai Bay in winter is about 7 m/s, and the maximum mean wind speed in the Laizhou Bay is slightly smaller, about 6m/s, which also occurs in winter.

4 Wind power density distribution of China's adjacent sea area

4.1 Distribution of China's adjacent sea area with water depth less than 60 m

China's nearshore shallow water area is vast, and area with water depth less than 60 m is about 560 000 km^2, which mainly distributes in the Bohai Sea and the Yellow Sea. The average water depth of the whole Bohai Sea is 18 m, and the water depth greater than 60 m only appears in the sea area near the Laotieshan water channel of the Bohai Stait, where the maximum water depth is 85 m, and the sea area with water depth less than 60 m is more than 70 000 km^2. There is a large area of shallow water in the Bohai Bay, Laizhou Bay and Liaodong Bay with water depth about 10m. The whole Yellow Sea area is about 38 km^2, and its average depth is 44 m and the maximum value is 140 m in the north of Chejudo Island. Sea area with water depth less than 60 m in Yellow Sea accounts for about 2/3 of the total area. And there is large area of shallow water in Jiangsu coastal waters with an average water depth less than 10 m.

4.2 The sea surface wind power density distribution of China's adjacent sea area

The sea surface wind power density of China's adjacent sea area displays seasonal variation obviously. The average wind speed reaches maximum value in December, among which the mean wind power density of sea area water depth shallower than 60 m is 434 W/m^2, and the mean wind power density of each shallow water area is equivalent in November and January. Generally speaking, wind power density is greater in winter (November, December, and January) which is mainly due to the Eurasian Continental high-pressure effect, and local wind speed is determined by the strong winter monsoon formed by Siberian High and Aleutian low pressure. Wind power density is smaller in summer (May, June and July). Among them wind power density reaches minimum value in May through all China's shallow water area, and average wind power density of water depth shallower than 30m is 101 W/m^2 which is the minimum value in each area and each month, but the value is still more than 100 W/m^2.

It is worthy of noting that in the shallow sea areas with water depth less than 20 m and especially 10 m, the wind power density in areas with water depth less than 10m is greater than that of other shallow waters in May, June, July and August. This is mainly due to the relatively strong local land and sea wind effect caused by the temperature difference between land and sea in summer, leading to that the mean winter power density in summer is greater in the sea area with water depth less than 10 m than that in the offshore sea area. In terms of resources, wind power density of Fujian is the largest in China's coastal provinces, so the feasibility to establish wind power plants in Fujian Province is the largest.

5 Suggestions of offshore wind power development

Under the premise of having the appropriate technology, sea wind energy has incomparable advantages than that on the land. And most of the population in our country is concentrated in the eastern coast, so the development of offshore wind energy in China's adjacent sea areas has an important strategic significance and practical significance.

While sea wind power has less pollution to the environment, but constructions of power stations in the sea may also cause some extent damage to the marine environment and reduce the sea area. Suspended sediment and waste produced during underwater construction will cause ecosystem environmental damage, and result in local water quality deterioration and marine organism losses, and cause adverse effects of different degrees on animal plankton and phytoplankton. In addition, in the process of power plant

construction, it will produce noise pollution and the deterioration of air quality (such as dust, smoke, smell), which will also have a negative impact on nearby residents, birds and other species nearby beach land.

Therefore, before the construction of offshore wind power plants, we must be in accordance with the marine functional zoning requirements strictly, consider the relationship between the variety of marine resources comprehensively, and make analysis according to the specific site, to choose the best way to develop, and to give appropriate preferential policies during the development [5].

6 Conclusion

In conclusion, characteristics of China's offshore wind power distribution and variation show that, multi-year mean wind speed distribution of climate state of China's adjacent sea area displays that mean wind speed is greater in the East China Sea and the South China Sea than that in the Yellow Sea and the Bohai Sea. Offshore wind speed is greater than the nearshore wind speed. The Taiwan Strait in China adjacent sea waters is the area with large wind speed. In China's coastal waters, wind speed in winter is relatively large, and it is small in summer, where the maximum wind speed happens in December, and the minimum wind speed is in May. The maximum wind speed values in each month all distribute in the Taiwan Strait neighborhood basically. Similarly, sea surface wind power density also has significant seasonal variation. In the shallow area, wind power density is larger in winter, and it reaches to a maximum value in December and the value is smaller with a minimum value in May. In summer, mean wind power density of sea area with water depth shallower than 10m is greater than that of the offshore area.

Wind energy resources have characteristics of low density, non-polluting, renewable energy, large reserves, wide distribution, etc. Wind utilization sites need to have big wind and long time duration, but to build power plants in the sea with such features will be more susceptible to marine disasters; it will require high project quality and the wind power development will have large difficulties. But facing the enormous pressure of energy shortage and environmental pollution, along with growing maturity of the theoretical and practical aspects, the wind power utilization is bound to have a broad prospect.

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中国毗邻海域海上风能资源分析

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摘 要：随着经济的发展，能源短缺问题日益严重，因此，海上风电能由于具有清洁、可再生、不占陆地面积、不存在噪音污染、储量大等优点，逐渐得到人们的关注，本文通过利用 1999 至 2009，共 10 年的 QuikScat 海上风场卫星资料，得到了多年中国毗邻海域平均气候态的年平均风场和各月平均风场，并分析计算得到了对应的风能密度分布，通过对风能密度的分布状况进行分析，概况总结了我国沿海海上风电能储备分布情况，并对中国沿海海上风电能的开发利用提出了对策建议。

关键词：可再生能源；海上风能；中国毗邻海域；风速；风能密度

Variations in tidal currents and suspended sediment concentration of the upper part of the North Channel of Changjiang Estuary over the past 10 years

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Abstract: The tidal current duration (TCD) and velocity (TCV) and suspended sediment concentration (SSC) were measured in the dry season in December, 2011 and in the flood season in June, 2012 at the upper part of the North Channel of Changjiang Estuary. They were assimilated with the measured data in 2003, 2004, 2006 and 2007, using the tidal range's proportion conversion. Variations in TCD and TCV, preferential flow and SSC have been calculated. Influences of typical engineering projects such as Qingcaosha fresh water reservoir, Yangtze River Bridge, and land reclamation on the ebb and flood TCD, TCV and SSC in the North Channel for the last 10 years are discussed. The results show that: (1) currently, in the upper part of North Channel, the ebb tide dominates; after the construction of the typical projects, ebb TCD and TCV tends to be larger and the vertical average ebb and flood SSC decrease during the flood season while SSC increases during the dry season; (2) changes in the vertical average TCV are mainly contributed by seasonal runoff variation during the flood season, which is larger in the flood season than that in the dry season; the controlling parameters of increasing ebb TCD and TCV are those large-scale engineering projects in the North Channel; variation in SSC may result mainly from the reduction of basin annual sediment loads, large-scale nearshore projects and so on.

Keywords: changes in tidal currents and suspended sediment concentration, preferential flow, data assimilation; large-scale engineering projects, Changjiang Estuary

Introduction

Variation of tidal current velocity (TCV) and suspended sediment concentration (SSC) in the estuary is a fundamental problem in the study of the estuary and the coast, as well as the basic content of the evaluation of the influence on the estuary after the large-scale

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projects of the estuary are implemented [1, 2]. Changjiang Estuary is a moderate-intensity tide estuary, which is "divided into 3 grades of branches and enters the sea in 4 branches" [3]. Shen Huan-ting [4] did a study on the changes of the TCV and SSC in the whole Changjiang Estuary in earlier years. Some scholars [1, 2, 5] analyzed SSC using the data of the Changjiang Estuary in 2003 and 2005. Most of researches on the North Channel (NC) [6-8] were the analysis of the evolution of the river trends, while the analysis and study on the changes of TCV and SSC were very few.

The NC is second-level bifurcation of Changjiang Estuary, and also is one of the four channels of the Changjiang Estuary into the sea. Under the effects of the runoff, tide currents, waves, the Coriolis force and other dynamic conditions, flow and sediment movement form is quite complex [9], which directly affects the safety of the estuarine and coastal projects. With the rapid development in last decade, dams and reservoirs built in basins, projects of water transportation and water and soil conservation make the volume of sediments in Changjiang Estuary decline sharply. Currently the volume of sediment load at Datong is 1.56×10^8 t annually on average [10]. The construction of innings, reservoirs, deep-water channels, bridges and other large-scale projects around NC has changed the original TCV and SSC structure of the upper of NC. The current status of TCV and SSC need to be studied urgently. According to the latest and historical data about TCV and SSC in the upper of NC during the flood and dry season in spring, this paper uses the tidal range's proportion conversion to analyze the variation of TCV and SSC, and then it discusses the influence factor of the variation of TCV and SSC in nearly 10 years, to provide the scientific basis for the construction and protection of the estuary, revetment, harbor and waterway projects.

1 Data and methods

1.1 Collection of historical data

In order to analyze the variation of TCV and SSC and discuss its influence factor at the upper of NC in the nearly 10 years, we collect the data of water and sediments at the upper of NC in February 1999 [5, 11], September 2002 [12], February (K0311) and July 2003, February and September (H0411) 2004, November 2005 [13], February (K0611) 2006, January and July (H0711) 2007, July 2010 [13], and also include the data of upstream and load sediment at Datong in the last 10 years [14]. The detailed locations of the measuring points are shown in Fig. 1.

1.2 On-site measurement

From 9th to 10th December 2011 and 6th to 7th June 2012, the Acoustic Doppler Current Profiler (ADCP) was used for a continuous flow fixed 26-hour simultaneous measurement at the north side of the Qingcaosha fresh water reservoir (S1), east of the Yangtze River Bridge (S2), south side of Chongming Dongtan (S3); from 11th to 12th December 2011 and 8th to 9th June 2012, a quasi simultaneous measurement was made on the north side of the Hengsha island (S4), and the measuring point position is shown in Fig. 1. Meanwhile the six-point method was used to measure speed and direction, and the vertical average velocity and direction were calculated based on the weighted average.

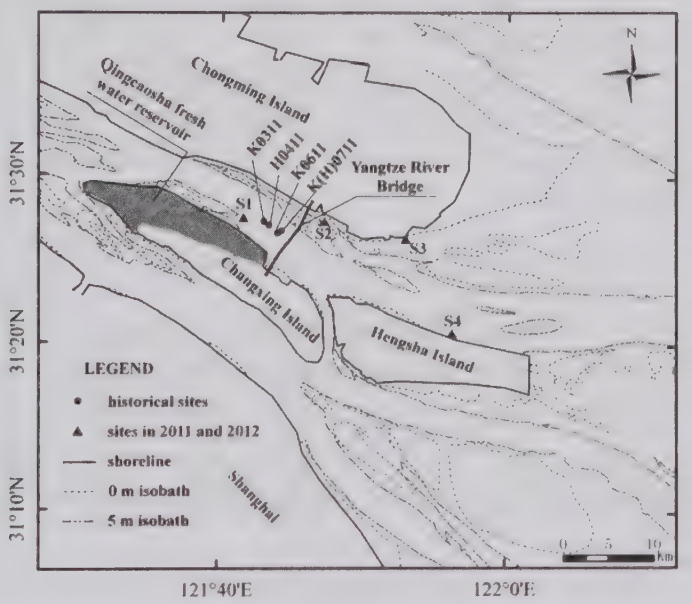

Fig. 1 Sketch map of the study area and observation sites

1.3 Water sampling and analysis of SSC

The stratified water sample collection is based on the measurement of "six-point" method: surface (0.5 m under the water), 0.2H, 0.4H, 0.6H, 0.8H, the bottom layer (0.5 m from the bed), when the water depth H<3 m , the "three-point" method is used, namely the surface, middle and bottom. According to each layer of water 600 ml, hourly stratified water sampling is sent to the laboratory filter by 45 um filter paper. After 105 °C incubator drying, and then the sediment concentration is placed in the drying cylinder for cooling 6 - 8 minutes and calculating the weighing of unit water sample, hourly vertical average sediment concentration using the six-point method to calculate the weighted average.

1.4 Data assimilation processing

The tidal flow comparison method is the same type of tide range under different flow velocities into the same range of velocity analysis. Measuring points near the tide station as the standard before the project, the flow velocity (tide range corresponding to the measuring point near the tide station in this time period) is measured after the project according to the proportional relationship between tide range conversions of relative flow velocity [11, 15].

1.5 Calculation of preferential flow

Preferential flow is first found in the Simmons' [16] study, that is, in the tidal estuary, the tidal velocity measurement process line point in the ebb discharge per unit width line envelope area is divided by the sum of absolute values of ebb and flow of the tides of single width, if the quotient is greater than 50%, the ebb tide dominates, and if less than 50%, the flood tide dominates, if 50%, flood and ebb flow is equal, and this position is called the stagnation point [17, 18].

Formula of preferential flow calculation is as follows:

Preferential Flow Average Ebb Tide Duration × Average Velocity of Ebb Tide / (Average Ebb Tide Duration × Average Velocity of Ebb Tide + Average Flood Tide Duration × Average Velocity of Flood Tide)

2 Current characteristics of water and sediments in the upper of the NC

2.1 The characteristics of tidal currents in the spring tide during the flood and dry season

2.1.1 The average duration of flood and ebb tide

For the upper of the NC (S1, S2, S3 and S4), the average duration of flood tide in the flood season is 3.7h, 5 h in the dry season (Fig. 2a); the average duration of ebb tide in flood season is 8.5 h, 7.7h in the dry season (Fig. 2b).

2.1.2 Vertical average velocity

In the tidal period, average vertical velocity of each measuring point in the flood season is greater than that in the dry season at the upper of the NC (Fig. 2c). The average vertical velocity of flood tide in the flood season is 0.56 m/s, 0.74 m/s in the dry season; the average vertical velocity of ebb tide in the flood season is 1.07 m/s, and 0.71 m/s in the dry

season.

2.1.3 Preferential flow

Preferential flow is greater than 0.5 during both flood and dry season (Fig. 2d) in the upper of the NC waters, which explains that ebb tide dominates in the upper of the NC.

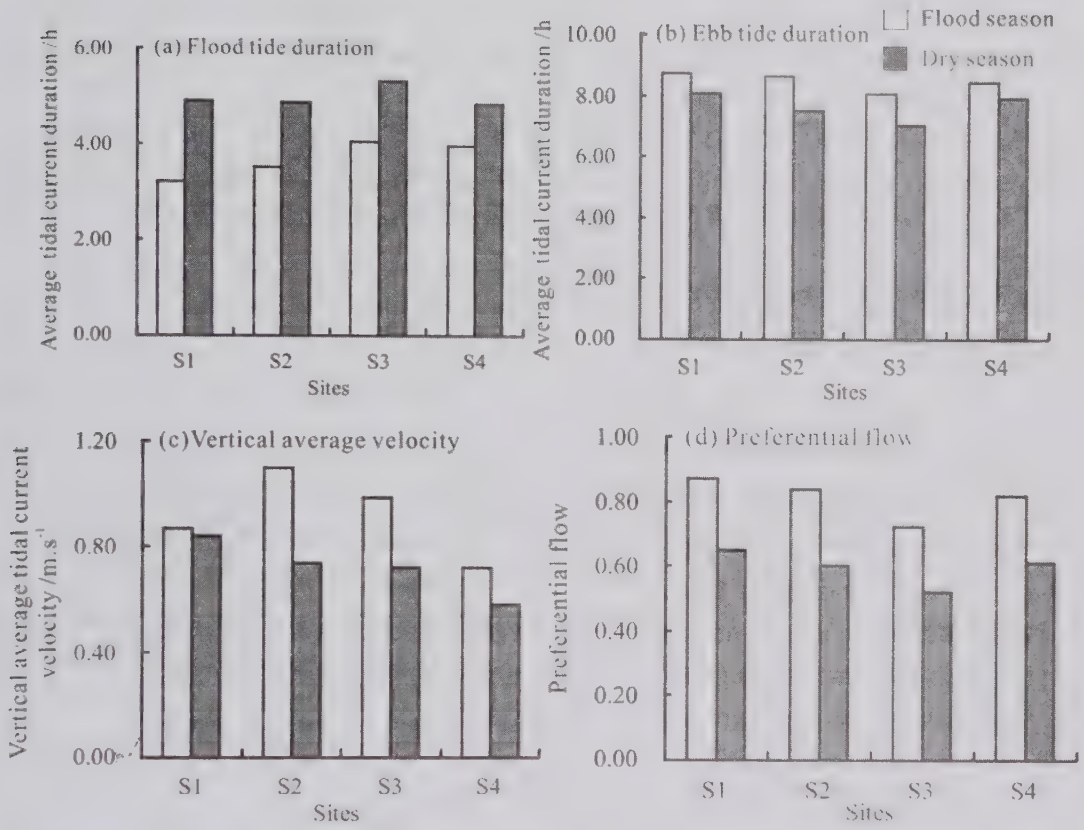

Fig. 2 Average flood duration(a) average ebb duration, (b) vertical average tidal current velocity, (c) and preferential flow (d) of sites in North Channel during the spring tide of flood season in June 2012 and dry season in December 2011

2.1.4 The vertical distribution of velocity

The average velocity of each layer from surface to bottom shows the trend of gradually decreasing in the upper of the NC, and the vertical distribution structure is roughly logarithmic velocity distribution [19] (Fig. 3). From surface to bottom, each measuring point having a larger velocity difference is between 0.24 - 0.33 m/s during the flood season (Fig. 3a); except that the velocity difference from surface to bottom in the dry seasons of north side of Hengsha Island (S4) is 0.07 m/s, and the velocity difference from surface to bottom of other points is between 0.26 - 0.43 m/s (Fig. 3b).

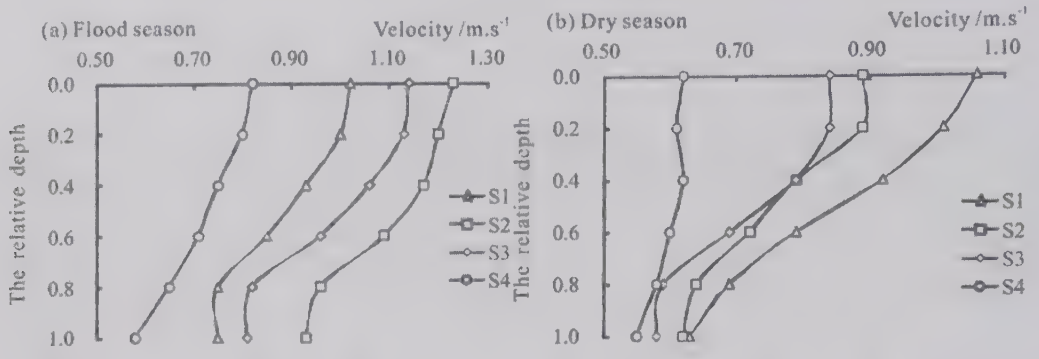

Fig. 3 Vertical profiles of average tidal current velocity of sites in North Channel during the spring tide of flood season (a) in June 2012 and dry season (b) in December 2011

2.2 The characteristics of SSC in spring during the flood and dry season

2.2.1 Vertical average SSC

In the tidal period, the vertical average SSC in the flood season is higher than that in dry season in the upper of the NC. Among them, vertical average SSC on the north side of Qingcaosha fresh water reservoir (S1) in the flood season is 0.286 kg/m^3, 0.670 kg/m^3 in the dry season; that at the east of Yangtze River Bridge (S2) in the flood season is 0.427 kg/m^3, 0.743 kg/m^3 in the dry season; that on the south side of Chongming Dongtan (S3) in the flood season is 0.707 kg/m^3, 1.096 kg/m^3 in the dry season; and that on the north side of Hengsha Island (S4) in the flood season is 0.204 kg/m^3, and 0.694 kg/m^3 in the dry season (Fig. 4).

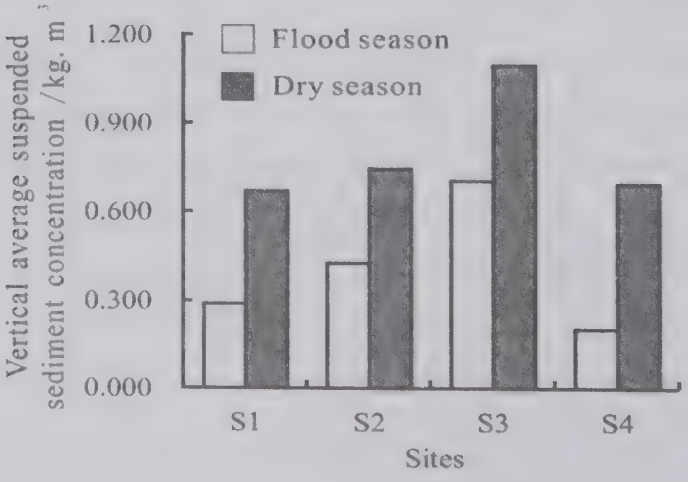

Fig. 4 Vertical average SSC of sites in North Channel during the spring tide of flood season in June 2012 and dry season in December 2011

2.2.2 Vertical distribution of SSC

Generally average SSC of each layer of the Changjiang Estuary from surface to bottom increases gradually, because the complicated hydrodynamic conditions make the vertical structure averages rarely conform to the Rouse formula of exponential distribution, and it can be divided into quasi linear, diagonal, parabolic type and mixed type [20]. During the flood season, the vertical distribution of SSC is parabolic in the south side of Chongming Dongtan (S3); in the north side of Qiangcaosha fresh water reservoir (S1) and east of Yangtze River Bridge (S2), the vertical variation range of SSC is small in the flood season, which shows the slash type; in the north side of Hengsha Island (S4), it presents hybrid (Fig. 5a). During the dry season, the overall vertical variation of SSC changes in a larger range, the vertical distribution in the north side of Qiangcaosha fresh water reservoir (S1) shows a parabola type, and that at the east of Yangtze River Bridge (S2), the north side of Hengsha Island (S4) shows the oblique line, and that at the south side of Chongming Dongtan (S3) shows a mixed type (Fig. 5b).

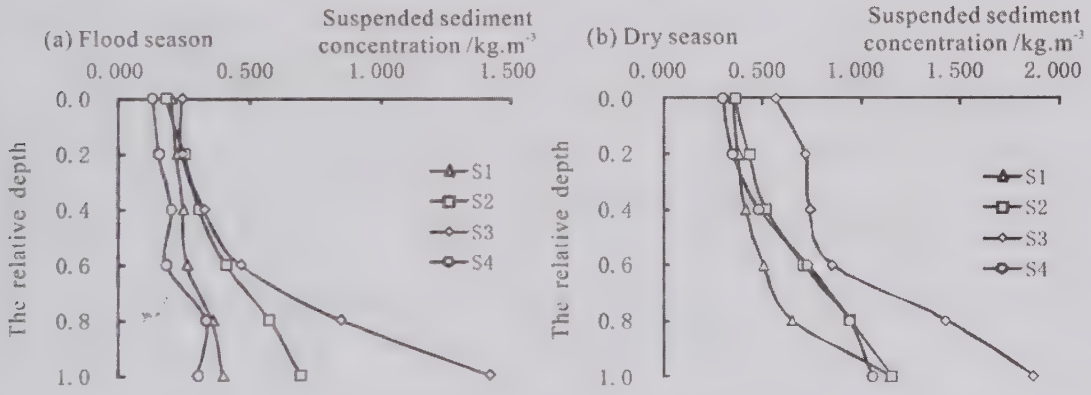

Fig. 5 The vertical profiles of average SSC of sites in North Channel during the spring tide of flood season (a) in June 2012 and dry season (b) in December 2011

2.3 The interrelated relationship between TCV and SSC

The tests in December, 2011 and June 2012 showed that the suspended sediment grain size was very small, and the range of the D50 grain size of suspended sediment in spring tide was 4 - 8 um, which belonged to silts and was affected largely by the flow velocity [21]. For example, the north side of Qingcaosha fresh water reservoir (S1) was used to explain the interrelated relationship between TCV and SSC in the upper of the NC. In the north side of Qingcaosha fresh water reservoir (S1), characteristics of vertical average SSC in the ebb tide were greater than that in the flood tide during the flood season, and the

ebb tide is less than the flood tide during the dry season. The peak value of SSC lagged the peak value of ebb or flood tidal current velocity for 1-2 hour, and the minimum of SSC also appeared after 1-2 hour at the end of ebb or flood tide (Fig. 6a, b). Overall, SSC movement in flood seasons was more violent than that in the dry season. However, the rate of change of SSC was smaller than that of tidal current velocity, and SSC depended on the tidal current movement.

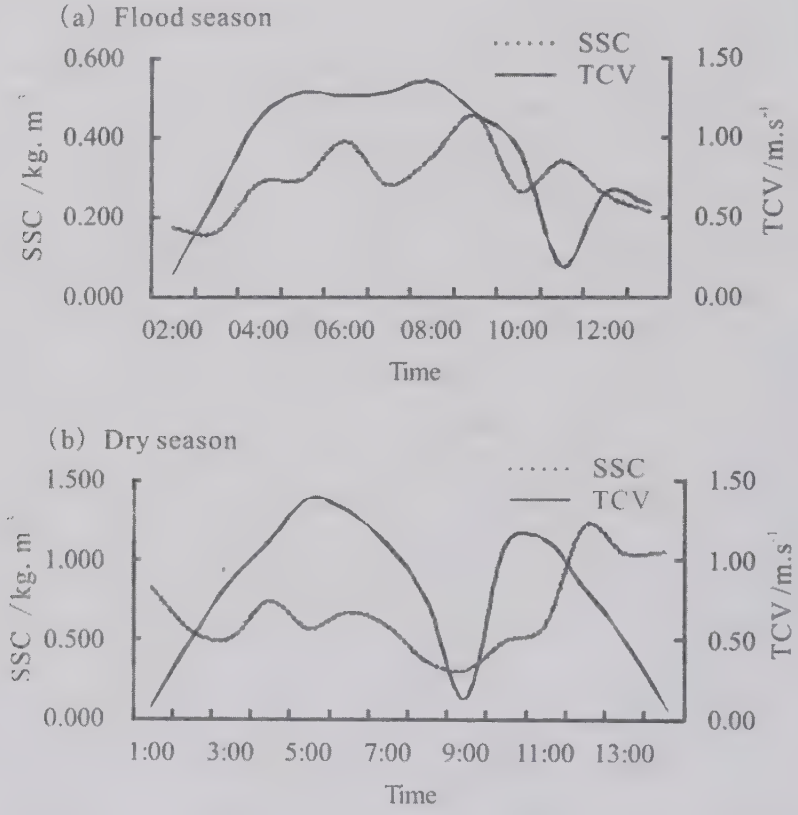

Fig. 6 TCV and SSC graphs of S1 site in the north side of Qingcaosha fresh water reservoir during the flood (a) and dry (c) season

3 The variation characteristics of TCV and SSC in the upper of the NC for last 10 years

3.1 Variation characteristics of tidal currents

3.1.1 Spring tides in the flood season

From 2004 to 2012, the advantages of ebb tides in the upper of the NC had been increased, and the average vertical velocities of flood tides and ebb tides were lessened,

and the flow velocity of flood tide obviously declined. In 2004, the average vertical velocity of flood tide was 0.87 m/s; in 2007, the velocity decreased to 0.79 m/s; and in 2012, it was greatly reduced to 0.43 m/s. In 2004, the average vertical velocity of ebb tide was 1.40 m/s; in 2007, the velocity fell to 1.04 m/s; and in 2012, it generally kept at 1.03 m/s. In 2004, the average vertical velocity of flood/ebb tides was 1.61. In 2007, it slightly fell to 1.32, and in 2012, it increased greatly back to 2.40 (Tab. 1).

3.1.2 Spring tides in the dry season

The advantages of ebb tides in the upper of the NC were strengthened from 2003 to 2011. Both the average vertical velocities of flood tides and ebb tides of 2011 were slightly bigger than those of 2007, but smaller than those of 2003 and the reduction of the velocity of the flood tides were more obvious. In 2003, the average vertical velocity of flood tides was 1.13 m/s; in 2006, it was reduced to 1.09 m/s; in 2007, it dropped substantially to 0.69m/s; and in 2011, it slightly increased to 0.78 m/s. In 2003, the average vertical velocity of ebb tides was 0.90m/s; in 2006, it rose to 1.02 m/s; in 2007, it fell back to 0.84 m/s; and in 2011, it was 0.89m/s. In 2003, the average vertical velocity of ebb/flood tides was 0.80; in 2007, it increased to 1.22, and in 2011, it was 1.14 (Tab.1).

Tab. 1 The vertical average TCV and SSC of the upper of North Channel in 2003 - 2012

Month/Year	Sites	Tide type	Vertical average TCV m/s			Vertical average SSC/kg.m^{-3}		
			Flood tide	Ebb tide	Ebb/Flood	Flood tide	Ebb tide	Ebb/Flood
9/2004	H0411	Spring tide in flood season	0.87	1.40	1.61	0.385	0.420	1.09
7/2007	H0711		0.79	1.04	1.32	0.368	0.325	0.88
6/2012	S1		0.43	1.03	2.40	0.267	0.292	1.09
2/2003	K0311	Spring tide in dry season	1.13	0.90	0.80	0.458	0.287	0.63
3/2006	K0611		1.09	1.02	0.94	-	-	-
1/2007	K0711		0.69	0.84	1.22	0.310	0.265	0.85
12/2011	S1		0.78	0.89	1.14	0.774	0.591	0.76

3.2 Variation characteristics of SSC

3.2.1 Spring tide in the flood season

The vertical average SSC in flood tide and ebb tide of the upper of the NC during 2004 to 2012 showed the average vertical SSC of tendency of gradual reduction. The vertical average SSC in tide rising in 2004 was 0.385 kg/m^3, reduced to 0.368 kg/m^3 in 2007 and to 0.67 kg/m^3 in 2012. In 2004, the average vertical SSC of ebb tide was 0.420 kg/m^3; in 2007, it decreased to 0.325 kg/m^3; and in 2012, it was reduced to 0.292 kg/m^3. In 2004, the average vertical SSC ebb/flood tide was 1.09; in 2007, it fell to 0.88; and in 2012,

it was 1.09 (Tab.1).

3.2.2 Spring tide in the dry season

From 2003 to 2011, the vertical average SSC in the flood tide and ebb tide of the upper of the NC showed the variation tendency of "reduction first and then increasing", and the variation range of SSC in ebb tide was relative larger than that of in flood tide. In 2003, the average vertical SSC of flood tide was 0.458 kg/m^3; in 2007, it fell to 0.310 kg/m^3; and in 2011, it increased to 0.774 kg/m^3. In 2003, the average vertical SSC of ebb tide was 0.287 kg/m^3; in 2007, it was slightly reduced to 0.265 kg/m^3, and in 2011, it increased back to 0.591 kg/m^3. In 2003, the average vertical SSC of ebb/flood tide was 0.63; in 2007, it increased to 0.85; and in 2011, it fell to 0.76 (Tab.1).

4 Analysis on the influence factor of the variation of TCV and SSC

Changjiang carries large amounts of suspended sediments and runoff into the East China Sea, which makes Changjiang Estuary with the main features of high turbidity and fine sediment, and the huge amount of suspended sediments and runoff have a significant impact on hydrology, sediment deposition and the ecological environment in the Changjiang Estuary and its adjacent waters [1, 2, 20]. Variations of TCV and SSC in the Changjiang Estuary are affected by seasonal runoff and SSC variation from basin, dam building, North Water Diversion Project, estuarine reclamation, reservoirs and port building, deepwater channel and bridge-building in recent years [23, 24].

4.1 Seasonal variation of watershed runoff and SSC

According to the statistics of Datong hydrological station over the years, runoff and sediment loads of Datong hydrological station are mainly concentrated from May to October (flood season), throughout the year accounting for 60% ~ 80% and 70% ~ 99% [13, 14]. From 1999 to 2012, Datong hydrological station measured sediment loads following the change of monthly runoff and change (Fig. 7a).In the upper of the NC, the vertical average velocity in the flood season is greater than that in the dry season, but the vertical average SSC in the flood season is less than that in the dry season (Fig. 7b). The monthly variation of vertical average velocity in the NC and monthly runoff in Datong hydrological station has the same trend during the flood season and dry season (Fig. 7a, b). From 1998 to 2009, ebb tide diversion ratio of South Channel (SC) and NC remained around 50% [24], so the influence factor of the flow velocity change in the flood season and dry season is not the diversion ratio in the NC, but the change of runoff in the flood season and dry season at Datong hydrological station. And the vertical average velocity of ebb tide is positively

related with the runoff of Datong hydrological station, while vertical average velocity of flood tide is negatively correlated with the runoff of Datong hydrological station.

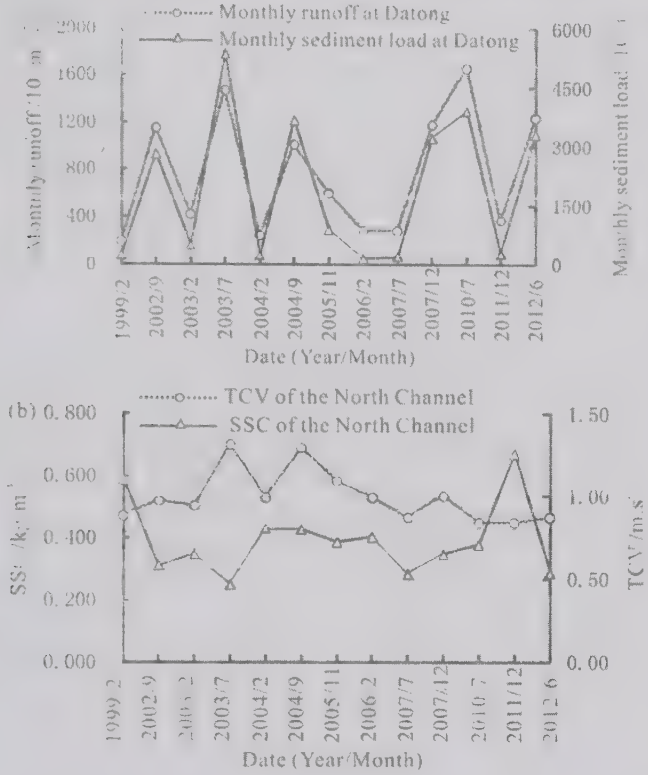

Fig. 7 (a) Monthly runoff and sediment load of the Changjiang Estuary measured at Datong, 1999 - 2012; (b) Vertical average TCV and SSC in the North Channel of the Changjiang Estuary at the spring tide, 1999 - 2012

The SSC sources of Changjiang Estuary include upstream sediments, coastal estuary sediments, shallow estuary, part of resuspension from the bed load and so on [25-26]. Although the upstream sediment is one of the estuarine sediment sources, the variation trends and SSC of the NC are not synchronized with monthly sediment load of Datong hydrological station in the flood season and dry season (Fig. 7a, b). This is mainly because the diversion is more and sediments less in the NC. The sediments cover the very few proportions, and dynamic conditions are given priority to the runoff, and the sediment resuspension is weak, which makes sediment concentration changes in the NC during the flood season and dry season are not more obvious than sediment concentration changes at Datong hydrological station during the flood season and dry season.

To sum up, monthly variation of runoff at Datong hydrological station during the flood season and dry season has a direct influence on the value of average vertical velocity in

the NC during the flood and dry season. Since the volume of sand distribution at the upper of the NC is small, SSC does not experience significant change in the NC during the flood season and dry season.

4.2 Large-scale engineering construction

Affected by the constructions of Zhongyangsha enclosure engineering, Qiangcaosha fresh water reservoir and Yangtze River Bridge, recently the width of NC has become obviously narrower, and there has been a certain degree of erosion in the north upper shoal [7]. Owing to retaining water of fracture surface, the main channel of the NC presents the broadening and degradation momentum [8].

In the early stage of Qiangcaosha fresh water reservoir in 2003 and 2004, when Yangtze River Bridge started working in 2004, river regime of the NC was basically in the state of natural evolution, and the average vertical velocity in the flood tide and ebb tide during the flood and dry season was faster (Tab. 2). In June, 2007, when Qiangcaosha fresh water reservoir started to construct, and Yangtze River Bridge was in the stage of construction, at that time, the river regime of the NC changed greatly under the effect of engineering, comparing with that in 2003 and 2004, and the average vertical velocity of ebb tide and flood tide during flood and dry seasons slightly decreased (Tab.1). In 2011 and 2012, Qiangcaosha fresh water reservoir and Yangtze River Bridge had been put into operation, at that time, changes in surrounding terrain of the NC engineering basically restarted to reach balance [27], and comparing with that in 2007, the average vertical velocity in the flood tide during flood season decreased, while the ebb tide was basically unchanged. In the dry season, the average vertical velocity of flood tides and ebb tides slightly increased (Tab. 1). In June, 2012, the velocity decreased may be related to the position of S1 measurement point, and S1 was located in the end of Qingcaosha, which had a certain distance from the main waterway, and velocity in the main waterway was relatively slow, but the advantage in the upper of the NC significantly strengthened.
It is visible that the upper of the NC and change time of TCV in the flood tide and ebb tide from 2003 to 2012 was exactly corresponding to that before the construction, under the construction and after the construction. We can speculate that Qiangcaosha fresh water reservoir, Yangtze River Bridge and the construction of surrounding reclamation project are the main reasons for the increase of ebb tide advantage of NC; while the change of SSC is affected slightly by the project construction.

4.3 The decrease of SSC from the drainage basin

Sediment concentration flowing to the sea in Changjiang Estuary during the flood season is significantly higher than that in the dry season (Fig. 7a), and water power of the

upper of the NC is mainly based on runoff, and runoff with a great number of sediments passes the waterway of the upper of the NC, then it continues to expand outwards. Since 2003, volume of runoff in Changjiang Estuary changed slightly, but sediment concentration flowing to sea has a trend of decrease [28-30]. The decreasment of the sediment concentration into the sea couples with the little variation of North-South Harbor sediment ratio [24], and sediment concentration spreading out of estuary from the upper of the NC will also be reduced. This fits with sediment concentration decreased in the upper of NC from 2003 to 2012 during the flood season. The runoff of Changjiang discontinuous reduction in the dry season weakened the runoff in the upper of the NC, with tidal current effect strengthening. Because the north side of Qingcaosha fresh water reservoir (S1) was located in the end of Qiangcaosha in December 2011, the sand body by the disturbance of runoff and tidal current dynamic became bigger, which made the water sediment concentration increase, and this may be the main cause of the sediment concentration bigger in the dry season.

In conclusion, decrease of vertical average SSC in the flood tide and ebb tide results mainly from the decrease of basin annual sediment load in the flood season, while the increase of vertical average SSC in the flood tide and ebb tide may be affected by sediment suspension due to waves in the dry season.

5 Conclusions

(1) At present, the preferential flow is more than 0.5 in the upper of the NC, which shows the ebb dominant advantage; vertical distribution structure type is roughly a logarithmic velocity distribution, and the sediment concentration vertical structure types are different due to different measuring points.

(2) The Changjiang Estuary water and sediment variation characteristics have obvious seasonal variation. In the upper of the NC, the vertical average velocity in the flood season is significantly greater than that in the dry season, and the vertical average SSC in the dry season is greater than that in the flood season. In the tidal period, vertical average SSC and TCV show a certain correlation, and vertical average SSC and TCV have a certain lag of 1 to 2 hours.

(3) After the construction of Qingcaosha fresh water reservoir, Yangtze River Bridge and land reclamation, the tidal current velocity decreases in the upper of the NC, and especially the velocity of flood tide decreases more apparently, with the ebb tide advantage enhancement. Due to a certain distance of the S1 measurement point from the main channel, the ebb tide velocity decreases. The average vertical SSC in flood tide and ebb

ode sediment during the flood season, while it increases during the dry season.

(4) Seasonal variation of runoff is the main reason causing flow velocity in NC to be more in the flood season and be less in the dry season; the construction of large-scale project is the main reason for strengthening the advantages of ebb tide of NC in the flood and dry season; the variation of SSC is relatively complicated, which is mainly influenced by the reduction of sediments in the basin, waves and other factors, and the project construction also has certain impact on the suspended sediment concentration at the same time.

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近 10 年来长江河口北港上段河道水域水动力及含沙量变化特征

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摘 要：基于 2011 年 12 月和 2012 年 6 月洪、枯季大潮北港上段河道水域的现场水文观测资料，以及 1999、2002、2003、2004、2005、2006、2007、2010 年历史水文测验资料，分析潮流历时、流速、优势流和含沙量等水沙现状和变化特征，并探讨近年来该水域水沙变化的主要影响因素。结果表明：（1）目前北港上段河道水域落潮占主导优势；青草沙水库和长江大桥建成后，落潮优势明显增强，洪季大潮涨、落潮垂线平均含沙量减少，枯季大潮涨、落潮垂线平均含沙量增多；（2）流域径流量的季节性变化是造成北港上段河道水域垂线平均流速洪季大、枯季小的主要原因；大型工程的建设是该水域落潮优势增强的主要影响因素；北港上段河道水域含沙量变化可能与近岸工程建设、入海泥沙量减少等因素有关。

关键词：水沙变化；优势流；大型工程；长江河口

Grain size distribution characteristics in surface sediments near the Dalian Bay and their hydrodynamic environmental implications

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Abstract: Based on grain size analysis for the offshore surface sediments of the Dalian Bay, the assemblages and distribution characteristics of grain size were acquired, and their sources and sedimentary environments as well as the dominant factors were also discussed preliminarily. The results indicate that the silt has the highest content of 52% in average, followed by sand of 34%. Clay is enriched in the central plateau subregion with the average content of 14%. They are distributed with the strap-shape from east to west, which is consistent with the distribution pattern of minerals there. The coastal shallow-water slope in the north of the study area is characterized by the enrichment of coarser deposition, indicating strong hydrodynamic conditions and nearby source. With water depth increasing southward, silt and clay fraction, mainly enriched on a subaquatic platform with better sorting, are considered to be transported far away. To the further south of the study area with the deepest water off another subaquatic slop, coarse fraction is the highest, implying strong hydrodynamic conditions induced by tide currents which pass in and out the Bohai Sea and Yellow Sea Warm Current that enters the Bohai Sea.

Keywords: surface sediments, grain size, Dalian Bay, hydrodynamic environment

Grain size is the representation of particle size of sediments whose distribution is restricted by factors of material source supply, motion distance, hydrodynamic condition and terrain. The mechanical analysis has been widely applied in aspects of sediment source tracing models (Gao et al., 1996; Saito et al., 2001; Yang et al., 2003; Liu et al., 2008), the study on sediment movement tendency (Cheng, 2000; Cheng et al., 2000; 2004) and sedimentary environment classification (Jiang, 2001; Wang et al., 2009). Presently, relatively intensive researches have been done on the Dalian Bay (Xu et al., 2004), Dayao

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bay (Wang et al., 2008), ecology and deposition (Liu et al., 2001; Wang et al., 2009; Li et al., 2011; Zhang, 2011), while few researches have been done on surrounding seas. The Dalian Bay, Dayao Bay and the whole peripheral seas have unique geographical location with significant regional characteristics and research significance as it is close to the material source and affected together by the Yellow Sea Warm Current and tides with many rivers nearby. This work aims to discuss about grain size distribution characteristics, transportation and hydrodynamic environment near the Dalian Bay to provide the basis for researches about material sources and sedimentary environments of North Yellow Sea, and then provide reference for the exploitation of oceanic mineral resources, marine environmental protection and harbor construction and renovation, according to the distribution of contents parameters and typical granularity. In addition, the sewage discharge along the coast, aquaculture and pollution discharge of channels and ships have generated contamination with different degrees to the sediments of this area (Wang et al., 2011; Zheng et al., 2012), therefore, the analysis of sediment sources will contribute to knowing the pollutant dispersion process of this area and providing basis for the marine environmental protection.

1 Overview of the research area

The Dalian Bay is located in the southwest of Liaodong peninsula, which is a semi-closed type bay (Fig. 1). The research area is starts from the Dalian Bay in the west and ends in Changshantou in the east. Depth of water (Fig. 2) is between 8.3m and 59.9m and the average is 30.6 m, with the deepest part in the western area. The depth of water becomes shallow gradually from the southwest (60m) to the northeast (20 m), being only lower than 10 m in the Dalian Bay and Dayao Bay. There are two subaquatic slops, including the first one in 20m and another one between 40 m and 28 m. The former one is flat while the other one is relatively steep. The central subaquatic plateau at about 28m is flat and broad. There are mainly bedrock coasts in the research area and small seasonal streams including Dawan River, Dengsha River and Malan River in the surrounding area. Rains there could wash over a large number of grains of sand into the sea (Gao et al., 1992), which is one of main sources of the research area. The hydrodynamic environment in the area is complicated because of the cooperative influence of Yellow Sea Warm Current, coldo west from the north of the Bohai straits (Miao et al., 1989; Liu et al., 2007), tidal currents (Hu, 1984; Han et al., 1994) and Liaodong Coastal Current (Wen et al., 2008). Ocean currents are mainly controlled by tidal currents, in which M2 tidal current absolutely dominates and accounts for more than 50% (Han et al., 1994). Researches on the north Yellow Sea sediments spread mainly focus on a mud wedge off the Shandong Peninsula

(Liu et al., 2007; 2009) and Yellow Sea Warm Current (Naimie et al., 2001; Xu et al., 2009; Zhang et al., 2008), but data on sedimentation and hydrodynamic characteristics near Dalian Bay have not been reported yet.

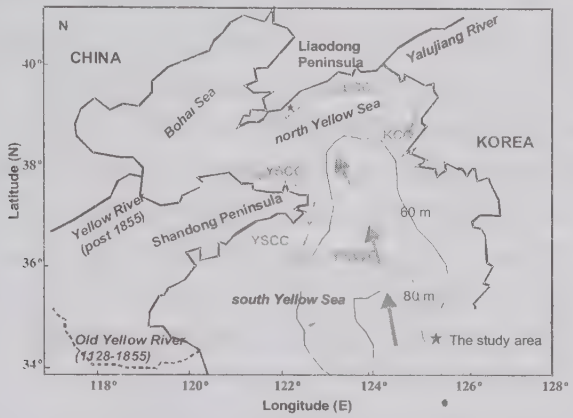

Fig. 1 Schematic map of the bathymetry and regional circulation pattern in the Yellow Sea and adjacent areas during the winter (referred to Liu et al., 2004; 2007; Yang and Liu, 2007). Water depth is in meters. SDCC: Shandong Coastal Current; YSWC: Yellow Sea Warm Current; LCC: Liaodong Coastal Current; KCC: Korean Peninsula Coastal.

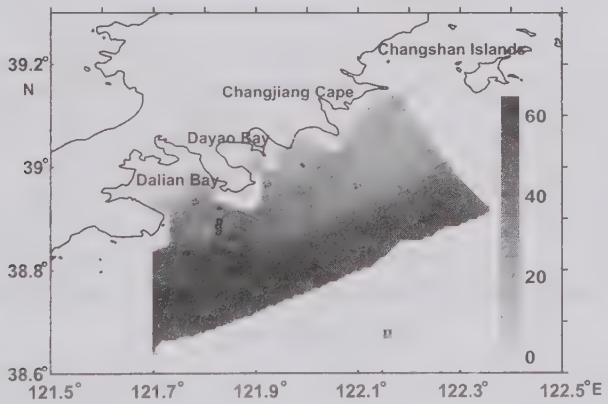

Fig. 2 Topography deepened progressively southward and southwestward

2 Materials and methods

A total of 183 box-samples in the north Yellow Sea (121.697 - 122.382°E, 38.617 - 39.166°N) (Fig. 3) were collected with the box sampler on the research vessel of "NO. 1 of Science" and positioned by the onboard GPS navigation system, and the sampling interval was 3 km.

Grain size anaiysis is conducted in accordance with relevant technical regulations of marine bottom characteristics exploration. Take appropriate wet samples, and add excessive 30% H2O2 and 0.25mol/L HCl solution one after another to remove organic matters and carbonate, and then rinse them for two times in a centrifugal way. Add a small amount of distilled water, and then measure them on the Cilas940L laser particle size analyzer made in France in the Institute of Oceanology of the Chinese Academy of Sciences after fully dispersing through the ultrasonic wave. The measurement range is 0.3 - 2000 μm and relative error through repeated measurement is less than 2%. Some of samples with gravels are sifted with the decimate sift whose aperture interval is 1/2 Φ, while screen analysis will be conducted for the particles larger than 2000μm and particle size analyzer will be used to measure those smaller than 2000μm. The grade standard adopts Uden--Windward's geometric system. Moment method is used to calculate granularity parameters.

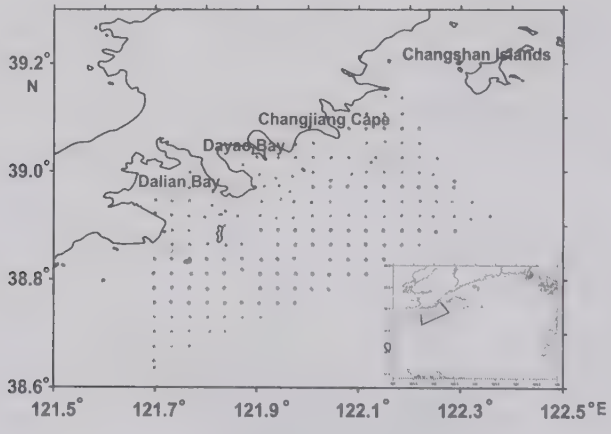

Fig. 3 Distribution diagram of sampling locations of surface sediments in the surrounding waters of the Dalian Bay

3 Results

3.1 Distribution of granularity parameters

Distribution characteristics (Fig. 4) of granularity parameters of surface sediments near the Dalian Bay are consistent with minerals (Li et al., 2009; 2011), as well as components, changing with the depth of water.

3.1.1 Mean size

Average value of particle size could reflect mean size of sediments and average

kinetic energy of transportation agent. Granularity parameters of sediments near the Dalian Bay are distributed in Fig. 4. Mean size ranges from 2.0Φ to 7.2Φ with an average of 5.3Φ. The distribution of mean size is consistent with water depth. The mean size is 5-6Φ, and it could be named as the medium silt according to Uddon-Wentworth grade scale in Tab. 1. In the middle area whose water depth is between 30 m and 40 m, fine silts are deposited with smaller particles (Φ >6). In southern part where water depth is more than 50 m, the deposition is relatively coarser (Φ<5), corresponding to coarse silts and fine sands. The particle size will become finer at first and then become coarser from the near-shore to offshore, demonstrating the non-homologous property of sediments in this region.

3.1.2 Sorting coefficients (Sort)

The sorting degree of sediments could be reflected by the standard deviation. Sorting coefficient near Dalian Bay is between 1.1 and 2.9 with an average of 2.06. It corresponds to poor sorting or relatively poor sorting according to Folk-Wolde (Tab. 2) (1957). Sorting is the worst far away from the shore, followed by that in offshore area, while sorting in the middle area (with the water depth of 30 m - 40 m) is relatively good. This discipline above is consistent with the mean size.

3.1.3 Skewness (Skew)

Skewness is a quantitative index for expressing symmetric degree of sediments distribution (Li et al., 1998), namely, positive value is coarse-bias while negative value is fine-bias (Zhang et al., 2007). The distribution of skewness is comparatively consistent with mean size also and most of them are positive-bias except several locations near the Sanshan Islands. There is an extremely positive-bias in the abyssal region of the southern area, as well as relatively small one in the middle area.

3.1.4 Kurtosis (Kurt)

Kurtosis, which is a significant clue for finding doublet, could describe the proportion of middle and tail expansion on granularity distribution curves. Kurtosis in this region ranges from 1.4 to 3.8 with an average of 2.63. An extremely positive-bias appears, with very wide peak, where poorest sorting and deepest water are in the southern part.

3.2 **Distribution of grain size composition**

According to the standard of Uddon-Wentworth, sediments could be classified to be the clay (>8Φ), silt (4-8Φ) and sand (-1-4Φ).

The distribution of granularity composition has been shown in Fig. 5. Silt, as the most abundant component near the Dalian Bay, occupies mostly 52% (11-81%) in

average. Following the silt are the sand (0-86%, with an average of 34%), and then the clay (3-32%, with an average of 14%). More sand but less clay content appears in the abyssal region that is far away from the shore, while the sand content decreases rapidly northward, accompanied by the increase of silt and clay contents. Sand content increases a bit again near the southern area of Liaodong peninsula, where the silt is still the main component. The triangle graphical method from Folk (Folk et al., 1970) will be used for the classification and naming. Sediments in the research area are mainly sandy-silts and silty-sands are mainly distributed in the southern abyssal region and the surrounding of Changjiang Cope.

Tab. 1 Classification of clastic sediments

Diameter /mm	Φ	Udden-wentworth component	
>256	<-8		Boulder
256-64	-8--6		Coarse gravel
64-4	-6--2		Medium gravel
4-2	-2--1		Fine gravel
2-1	-1-0	Extremely coarse sand	
1-0.5	0-1	Coarse sand	
0.5-0.25	1-2	Medium sand	Sand
0.25-0.125	2-3	Fine sand	
0.125-0.0625	3-4	Extremely fine sand	
0.0625-0.031	4-5	Coarse silt	
0.031-0.0156	5-6	Medium silt	Silt
0.0156-0.0078	6-7	Fine silt	
0.0078-0.0039	7-8	Extremely fine silt	
<0.0039	>8		Clay

Tab. 2 Grade table of sorting degrees

Sorting grade	Excellent sorting	Good sorting	Medium sorting	Poor sorting	Extremely poor sorting
Sorting coefficient	<0.35Φ	0.35-0.71Φ	0.71-1.00Φ	1.00-4.00	>4.00

3.3 Frequency distribution curve and probability cumulative curve

According to the average distribution principle, 3 or 4 samples from different types (Fig. 6) are chosen to draw frequency distribution curve (Fig. 7) and probability cumulative curve (Fig. 8). The probability accumulation curve is generally constituted by suspension

components and jumping components while several ones show traction components.

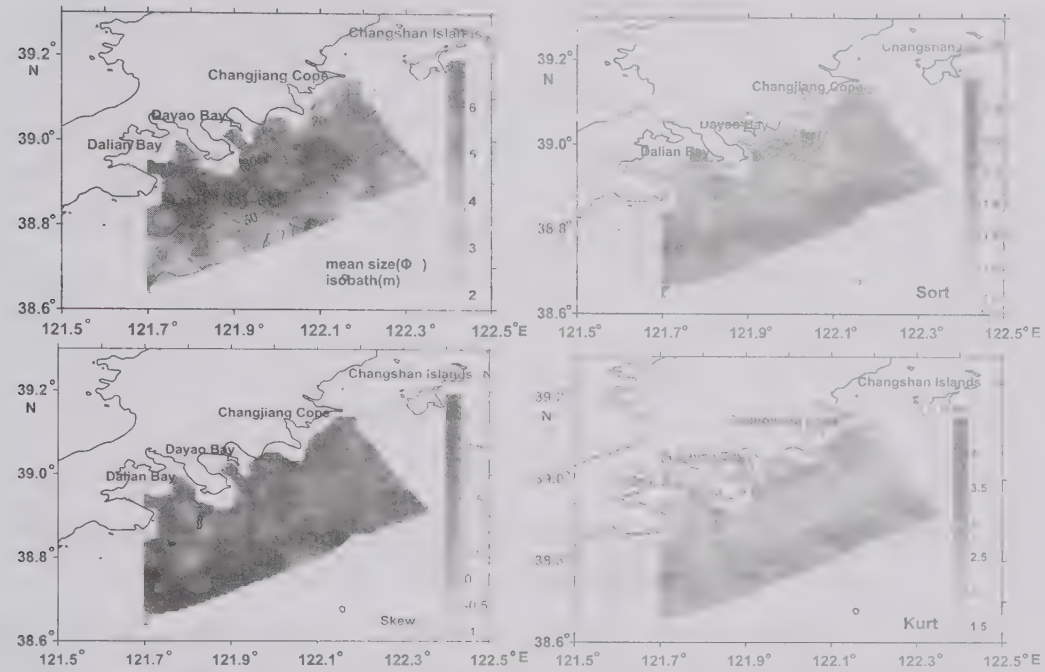

Fig. 4 Distribution diagrams of granularity parameters of sediments near the Dalian Bay

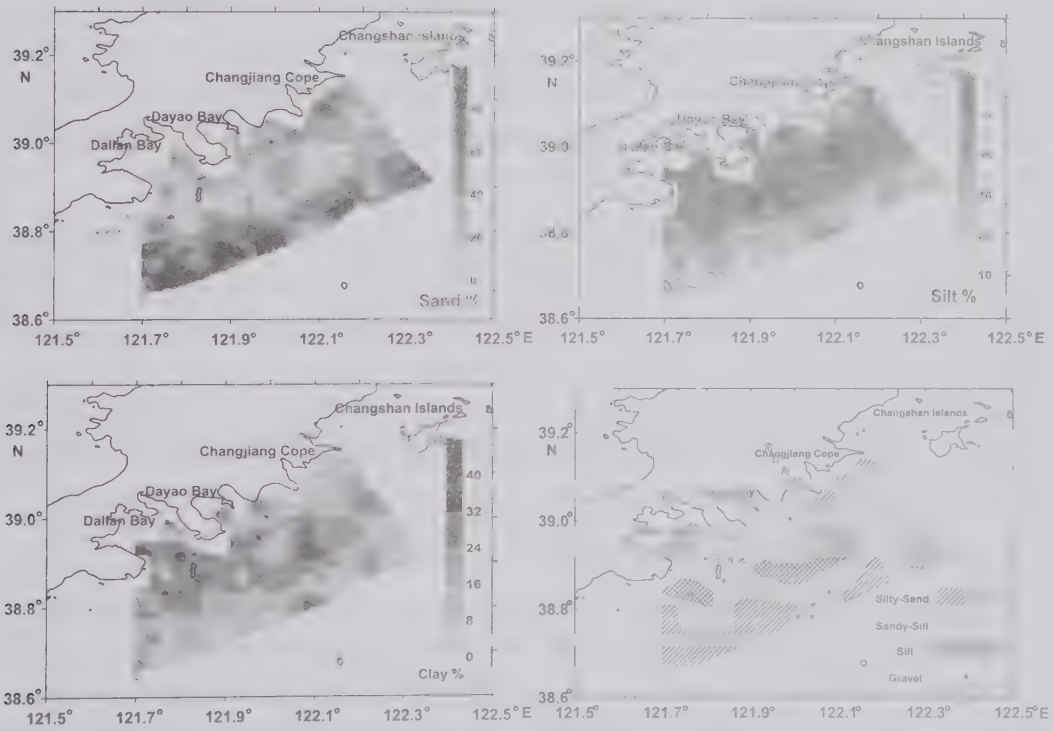

Fig. 5 Distribution diagram of granularity composition of sediments near the Dalian Bay

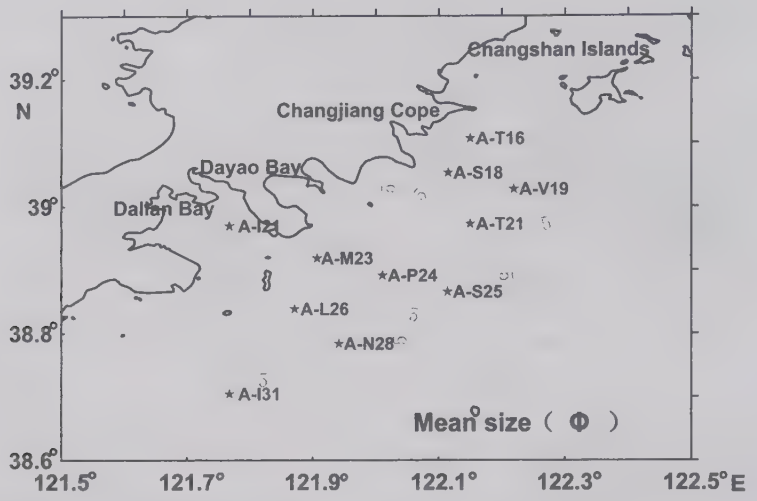

Fig. 6 Diagram of samples chosen in different sediment types according to the average distribution principle

Particles in the southern deepwater far away from the shore are relatively coarse, and the frequency distribution curve there mainly presents the unimodal pattern (Fig. 7a). Mode is between 2.0Φ and 3.0Φ and the individual will have extremely high value as 0.7Φ. In the probability cumulative curve (Fig. 8a), the content of jumping components is between 40% and 80% and the demarcation point between jumping components and suspension components is approximately 3-4Φ. The probability cumulative curve of sediments varies relatively significantly and so are the sorting coefficients of all components.

Coarse particles always have advantage in the slope along the coast in the north. Frequency distribution curve (Fig. 7b) mainly presents the bimodal pattern. Mode ranges from 3.5Φ to 4.0Φ and 1.8Φ to 2.0Φ, while the individual is 6.2Φ. In the probability cumulative curve (Fig. 8b), the content of jumping components, which are generally between 30% and 60%, increase a bit comparing with that in the middle part. The demarcation point between jumping components and suspension components is about 2-4Φ and sorting coefficient varies little there, especially in suspension components.

Particles are finest in the central plateau subregion compared with those in the north part and south part, and frequency distribution curve presents the unimodal pattern (Fig. 7c). Mode ranges from 3.4Φ to 4.0Φ while the individual is 6.4Φ. Coarse components in the probability cumulative curve (Fig. 8c) decrease obviously. The contents of jump components are mainly below 30% and the demarcation point between jumping components and suspension components is about 4Φ.

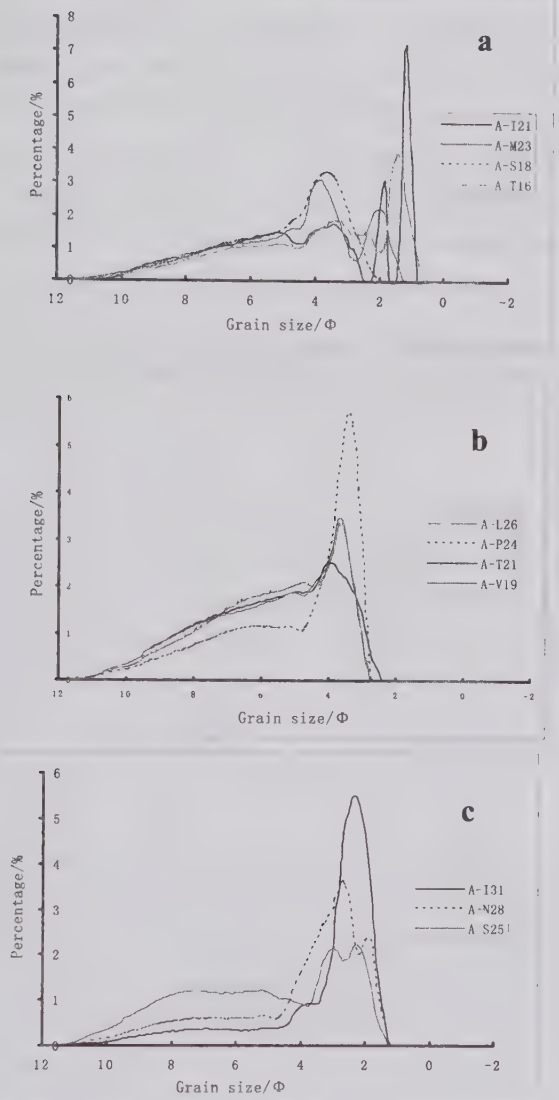

Fig. 7 Frequency distribution curve of sediments near the Dalian Bay

4 Analysis of Sedimentary Environment

To compare the terrain with the granularity distribution, the high content of sand is basically located in the areas where the water depth is relatively big in the south area, as well as the near-shore bank slop. While the silts and clays have absolute advantages in the flat plateau subregion, especially the silt.

Generally, distribution characteristics in the local area are controlled by combined

actions of provenance and hydrodynamic conditions. On the southern deepwater slop, particles are relatively coarse (Φ>5 in average), and sorting is poor (>2.1). Skewness in most samples is dissymmetric positive (>1.6), and kurtosis is generally more than 2.5. The probability cumulative curve is usually employed to reveal the relationship between deposition characteristics and transport force. So some tiny variations of transport condition could also be reflected on the curves (Zhou et al., 2008). The frequency distribution curve of this area mainly shows as the sharp unimodal pattern, reflecting strong hydrodynamic conditions and unstable sedimentary environment. Probability cumulative curves among different samples, as well as sorting coefficients among different components, vary significantly. A strong hydrodynamic condition and variable sedimentary environment are suggested because of the high content of jumping components content.

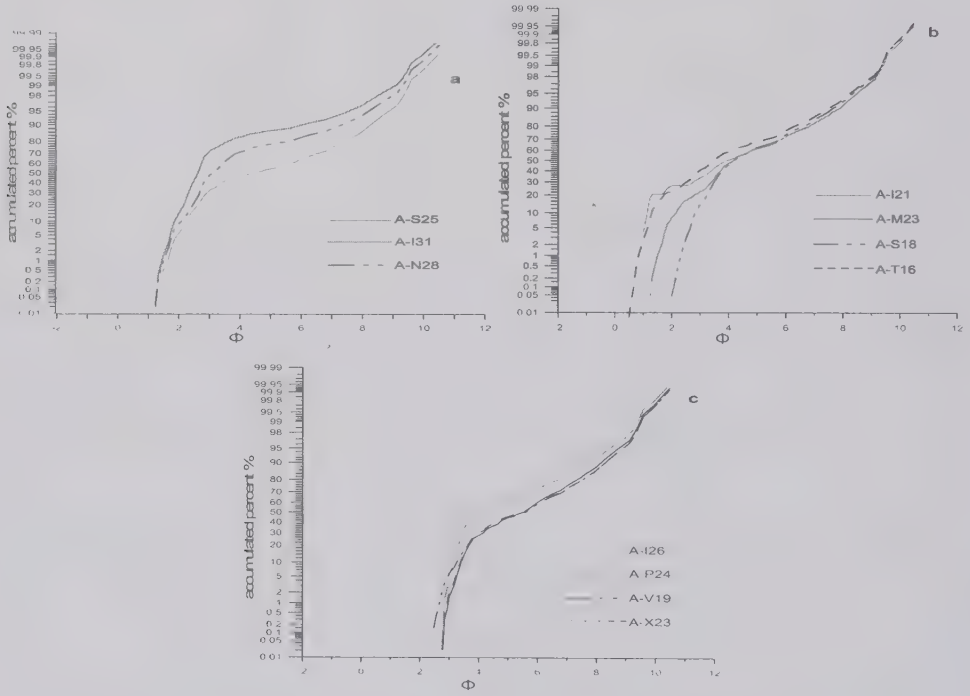

Fig. 8 Probability cumulative curve of sediments near the Dalian Bay

On the coastal shallow-water slope, most of samples are the positive skewness (1.0-1.6), except several samples in the the Dalian Bay. Frequency distribution curve mainly presents the bimodal pattern, with the mode ranging from 3.5Φ to 4.0Φ and from 1.8Φ to 2.0Φ. Jumping component contents in this shallow-water slope are higher than that in the middle plateau. Sorting coefficients among different samples, especially suspension components, varies more slightly, revealing complicate provenance and strong hydrodynamic condition.

Particle is the finest in the plateau subregion of the middle area compared with southern and northern part near the Dalian Bay. The sorting coefficients are always below 1.9, and most skewness is positive. The frequency distribution curve presents unimodal pattern, and among different samples, the probability cumulative curves, as well as sorting coefficients are analogous, revealing a stable sedimentary environment. It is the steep probability cumulative curve and high content of jumping components that suggest active particles on this plateau (Li et al., 1999). The value of positive skewness is smaller, evenly negative skewness, showing a long-distant transport.

The particles in the research area are taper off from the shore to the external. The mean size in the Dalian Bay and the Dayao Bay is small owing to the weak hydrodynamic condition there. On the coastal shallow-water slope, provenance and hydrodynamic conditions are comparatively complicated because there are many bays and islands, leading to a lot of erosive substances (Wang, 2009). To the sea, accompanied with water depth increase, the hydrodynamic condition become weak, and particles become fine, gradually. Particles are relatively coarse in the abyssal region far away from the shore as it is close to the mud wedge from the Yellow River and affected by the circulation system of the Yellow Sea.

5 Conclusions

1) Granularity compositions of sediments in the research area are mainly sands and silts, while the clay content is relatively small and is enriched in the central plateau subregion with average content of 14%. Sand content is relatively high on the deepwater slope, directly resulting that average grain size there is coarsest. Silt is relatively rich. However, the sand is deficient in the central plateau subregion, resulting in the finest particles and excellent sorting there.

2) There is a high consistency between the distributions of grain size and the depth of water near the Dalian Bay. Particles on the coastal shallow-water slope are coarser, owing to the complicated provenance and hydrodynamic conditions. Sedimentary environment is relatively stable and fine particle matters from far away accumulate along with the increase of water depth. The southern deepwater slop accommodates more coarse particles under the influence of circulations.

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大连湾附近海域表层沉积物粒度特征及水动力环境指示

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摘 要：对大连湾、大窑湾外及其附近海域表层沉积物进行了粒度分析，揭示了该区域大致的沉积特征。结合相关的地质水文资料，探讨了其控制因素，同时对沉积环境进行了初步分析。研究区沉积物粒度组分以砂（平均含量 34%）和粉砂（平均含量 52%）为主，粘土含量比较少（平均含量 14%），且主要分布在研究区中部水下台地之上，各组分相对含量呈东西向条带状分布，与地形分布趋势较为一致。北部近岸水下岸坡区，水深较浅，距离物源区较近且水动力条件复杂，沉积物粒度较粗；向南随水深增加水动力减弱，东部为一水下台地，沉积物粒径偏细。分选较好，粉砂和粘土组分在该区域最为富集，沉积物可能来自于通过东部海域自西向东进入研究区的远源物质；研究区南部水深增加，又出现一水下岸坡，其下地形趋于平坦，该区域在黄海环流体系的作用下，接受了较多来自包括山东半岛水下三角洲的粗颗粒物质。

关键词：表层沉积物；粒度；大连湾

Dynamic response analysis of the submarine suspended pipeline impacted by dropped objects based on LS-DYNA

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Abstract: Based on ANSYS/LS-DYNA, the dynamics analysis software, and using nonlinear dynamic finite element method, the process of a submarine pipeline impacted by dropped objects is simulated. Some conclusions are drawn: First, the damage depth of suspended pipe is smaller than that of the bare pipe in case of the same fall energy, and with the increase of fall energy, the difference grows; Second, with the falling object's speed and mass rising, the deformation of pipeline intensifies at the impact site, and the maximum vibration amplitude of submarine pipeline increases; Third, when the fall energy is equal, the smaller the contact area of falling objects and pipeline is, the greater the damage depth of pipeline becomes; Fourth, changes of seabed soil parameters (shear elastic modulus, internal friction angle, density) have less influence on the suspended pipeline's dent depths and maximum vibration amplitude.

Keywords: suspended pipeline, impact, dent depths, dynamic response

1 Introduction

Subsea pipeline's safety during the period of running is an important condition for the exploitation of offshore oil and gas. In the process of installation and operation, submarine pipeline often collides with the falling objects owing to other activities such as anchor dropping or fishing, and finally pipelines are damaged. In recent years, the development of oil and gas resources is going ahead to the ocean massively, and subsea pipeline accidents such as fatigue damage and impact damage began to draw people's attention gradually. Among them, the impact damage is caused by accidental loads, and dropped objects from offshore platform or ship and accidental anchor will cause the damage of submarine pipelines. For submarine suspended pipelines, the impact of dropped objects will also cause the span section's vibration in vertical direction

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which is the main factor for pipeline's fatigue failure. Therefore, for submarine suspended pipelines, such damage caused by dropped objects is particularly obvious. (Wang Zaiming, 2010; Tan Jian, 2008)

Analysis of submarine pipeline's collision problem should not only consider the contact between dropped objects and pipelines, but also consider the interaction between pipelines and soils, which is a highly nonlinear problem. Domestic and foreign scholars have done a lot of research on submarine pipeline's impact failure. At abroad, the current DNV standard specified the deformation conditions of submarine pipelines under the impact of trawl fishing gears or foreign objects, and gave the relationship between the maximum allowed depth of permanent deformation and pipe diameter, wall thickness, yield strength. However, the standard did not consider the energy absorbed by seabed, dropped objects, and ignored the influence of nonlinear factors in the process of collision, so the results were not accurate.（DNV，1996；DNV-RP-F107，2001）Elhnas first proposed the semi empirical formula of impact loads and damage depth at the hit point.（Elhnas et al., 1983） Pal used finite element methods to carry on the numerical simulation analysis of submarine pipeline with injury.（Pal et al., 1999）Wierzbicki et al. considered tubular initial axial stress, and gave a calculation formula about damage depth and energy absorbed by pipelines.（Wierzbicki et al., 1998）

In the domestic research, in view of energy absorbed by pipelines after the collision, Su Jing and Guo Zhenbang calculated the damage depth of pipeline after the impact, but they did not consider the interaction between pipe and soil, and did not give the dynamic response rules. (Su Jing, 1999; Guo Zhenbang et al., 2007) Applying Ramberg-Osgood model to the seabed soil, Yang Xiujuan used three dimensional nonlinear finite element method to simulate the process of exposed submarine pipelines impacted by dropped objects. (Yang Xiujuan et al, 2011; Yang Xiujuan et al., 2009)Using nonlinear spring to simulate the interaction between the soil and pipe, Huang Xiaoguang, discussed the changes in stress and strain of submarine suspended pipeline after the collision.（Huang Xiaoguang et al., 2012）Bai Junlei studied on the damage behavior of exposed submarine pipeline after the impact using Druckcr-Prager model to the seabed, and influences of some factors on the damage depth of the exposed pipeline were analyzed, such as radius-thickness ratio, shape of dropped object, the thickness of concrete and embedded depth. (Bai Junlei et al., 2013).

Currently, the majority of scholars use finite element analysis software to simulate collision damage of exposed submarine pipeline, but only a few studies on the numerical simulation of submarine suspended pipeline are carried out. Huang Xiao guang, used nonlinear spring to simulate the seabed soil and studied the behavior of stress and strain of

submarine suspended pipeline after the collision. In this paper, by means of non-linear finite element software ANSYS/LS-DYNA, a three-dimensional model about pipeline and seabed was built, and pipe-soil interaction was considered. Also, the dynamic response process of submarine suspended pipeline was simulated, and influences of some parameters on the damage depth and dynamic response amplitude of the suspended pipeline were analyzed, such as impact velocity, impact mass, shape of impact object and seabed parameters.

2 The physical model of subsea suspended pipeline

2.1 The geometric parameters and material properties

The design of geometric parameters refers to subsea pipeline engineering design reference parameters. The diameter of submarine pipeline is 0.508 m, wall thickness 0.012 7 m, and pipe material X65. The material properties are shown in Tab. 1. Due to the current scour, span section appears, and the span length is 10 m, and the penetration depth of the pipeline is 30 m (about 60 times of the diameter). This paper uses kinematic hardening elastic-plastic model to simulate subsea pipeline.

Tab.1 Material parameters of pipe

Steel grade	Density/kg.m-3	Elastic modulus/Gpa	Poisson's ratio	Yield strength/Mpa	Shear strength/Gpa
X65	7850	210	0..3	448	1.7

When the collision problem of submarine pipeline is analyzed, the interaction between the pipe and the soil should be considered, so a reasonable seabed model is very important to the accuracy of simulation results. Because the seabed's compression yield strength is much larger than the tensile yield strength, not only the elastic deformation occurs, but also the plastic deformation. This paper chooses Drucker-Prager elastic-plastic finite element model to simulate the seabed. The D-P model's material parameters are shown in Tab. 2.

Tab. 2 Material parameters of the seabed's D-P model

Density/kg.m-3	Elastic shear modulus/Mpa	Poisson's ratio	Friction angle/°	Cohesive force/KN	Dilatancy angle/°
2040	25	0.3	37	18	30

The main parameters of the dropped object as a rigid body are as follows: density is 7 850 kg/m^3; elastic modulus is 210 Gpa; poisson's ratio is 0.3. In addition, this paper adds the additional water mass to the dropped object in the form of density (Wang Zili et al., 2002) and obtains the equivalent density:

$$\rho_e = \rho_d \cdot (1 + \frac{\rho_w}{\rho_d} \cdot C_a)$$

where C_a is the added mass coefficient.

2.2 The finite element model

The finite element model of submarine suspended pipeline is shown in Fig.1. For suspended pipelines, SHELL163 element is used to build the suspended pipeline model, also set the suspended pipeline's material properties. For dropped objects, SOLID164 element is adopted to build the dropped object rigid model, also set the dropped object's material properties. For the seabed, SOLID164 element is used to build the seabed model, also set the seabed's material properties.

The boundary conditions are set as follows: upper surface is the free boundary, with no constraints; lower surface has fixed vertical displacement, and side faces have fixed lateral displacement, that is to say, if the plane is parallel to the YOZ plane, then it will constrain X direction displacement; and if the plane is parallel to the XOY plane, then it will constrain Z direction displacement. Submarine pipeline is fixed at both ends of the axial displacement.

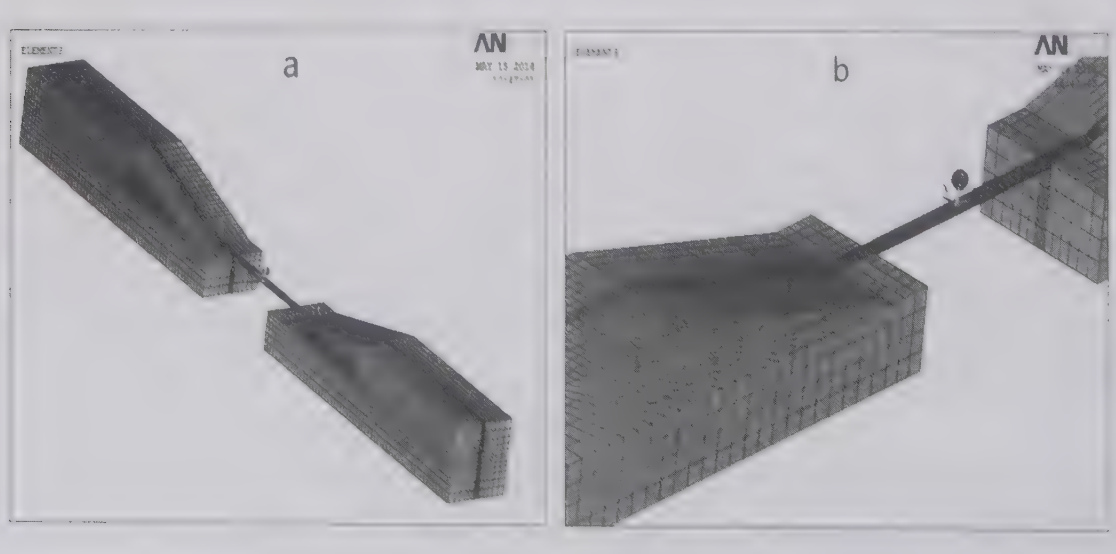

Fig. 1 Finite element model of submarine suspended pipeline

3 Numerical simulation of the impact process of submarine suspended pipeline

In this paper, ANSYS/LS-DYNA finite element dynamic analysis software is used to simulate the falling impact process of submarine suspended pipeline. In ANSYS/LS-DYNA preprocess, we set up the collision model of seabed-pipeline-dropped objects, and then add loads and build the master-slave contact interface of pipelines and seabed, pipelines and dropped objects, then K document is generated and submitted to the LS-DYNA solver to calculate.

3.1 Verify the accuracy of the calculation results

Since the calculation of DNV specification and empirical formula of pipeline damage depth are based on submarine exposed pipelines, this paper established a three dimensional finite element model of exposed collision and calculated the damage depth of exposed pipelines, then compared the calculated results with the results of empirical formula to verify the accuracy of the results. As shown in Fig.2, the results of simulation and those empirical formulae basically have the same trend, and the calculating values are identical with empirical ones.

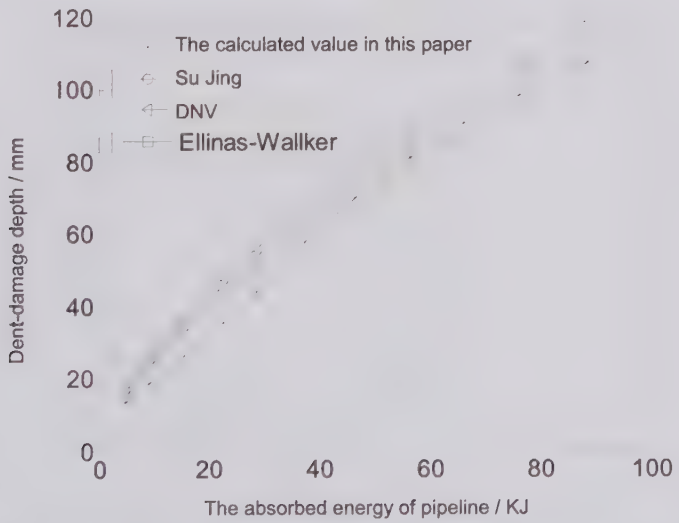

Fig. 2 The results of simulation compared with the results of empirical formula

3.2 Time history analysis of depressed deformation

When the weight of dropped object is 1000Kg, the impact velocity is 7m/s, and suspended length is 10m. The deformation diagram of suspended pipelines at different

time in the cross section is shown in Fig. 3.

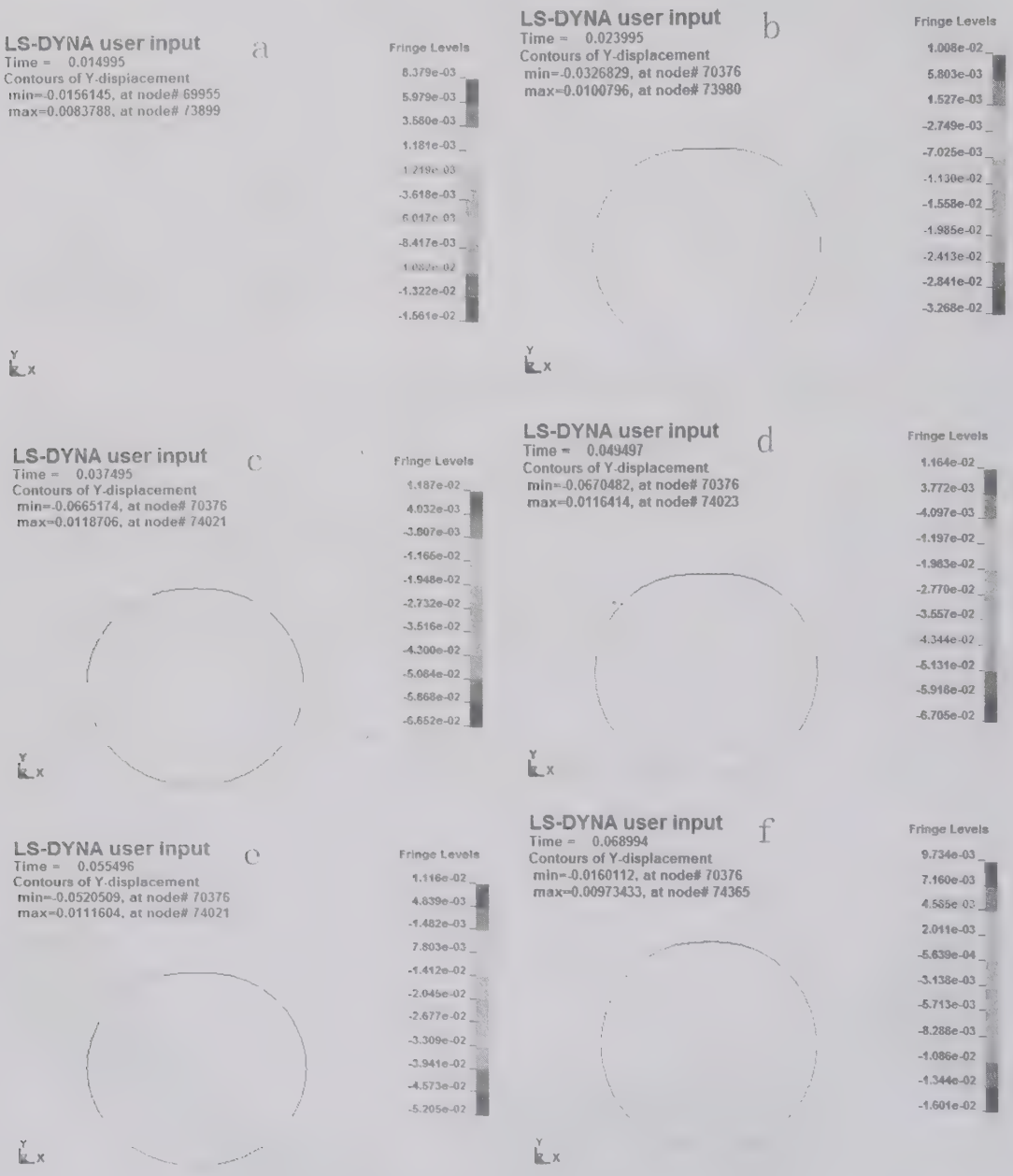

Fig. 3 The deformation diagram of pipes at different time in the cross section

After the collision, elastic deformation appears firstly, then the deformation comes into plastic deformation range, the pipe begins to produce irreversible plastic deformation on the top. When time is 0.024s (Fig. 3b), the depressed deformation of pipeline reaches a peak (0.026m); then dropped objects begin to rebound, and the deformation in the elastic

range gradually is restored. When it is 0.049s (Fig. 3d), due to the occurrence of vibration, collision happens again for the second time, and the depressed deformation increases again, reaching a new peak (0.023 m). Afterwards the dropped objects continue to rebound, and pipeline and dropped objects no longer collide, also the depressed deformation of the pipeline is stabilized with a 0.0075m plastic deformation dent staying in the pipeline eventually.

For analyzing the results, this paper chooses the vertical displacement difference of node A and node B as dented depths, which are located in the top and bottom of the impact center section of the pipeline.

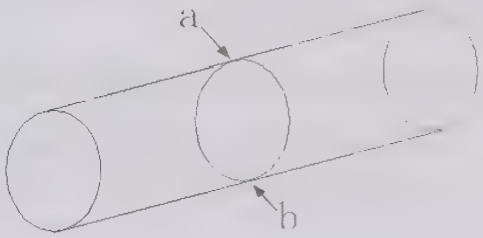

Fig. 4 Sketch map of node a and b

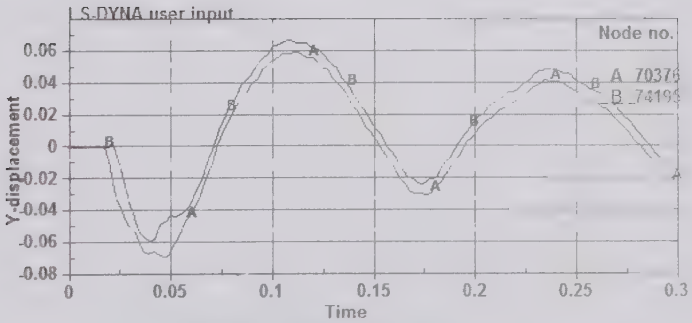

Fig. 5 Vertical displacement-time of node a and b

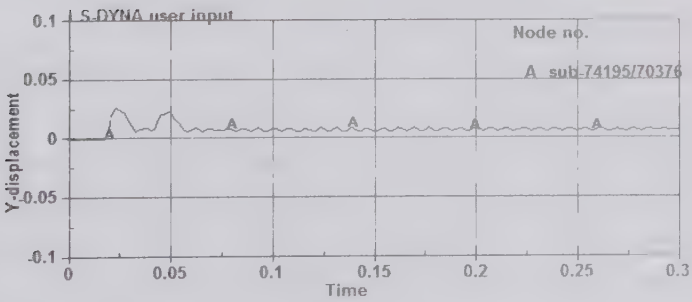

Fig. 6 Displacement difference-time of node a and b

4 Analysis of influence factors of the submarine pipeline damage

There are many factors causing the damage of pipeline, of which the main factors are the impact energy, the shape of dropped objects, the thickness of concrete layer, the depth of burial etc. This paper mainly analyzes the effects of impact energy, shape of dropped objects and seabed parameters on submarine pipeline. According to DNV, there are two main factors causing change of impact energy, which are the impact velocity and mass. The contact area between dropped object shape and submarine pipeline is the main factor for the effect of the shape. Cubical litter, spherical litter and conical litter are studied separately in this paper. In addition, this paper compares the depressed deformation of suspended pipelines with that of exposed pipelines.

4.1 Comparison of suspended pipeline and exposed pipeline

Under different impact velocities, the dent depths of suspended pipeline and exposed pipeline are calculated, and the results are shown in Fig. 7.

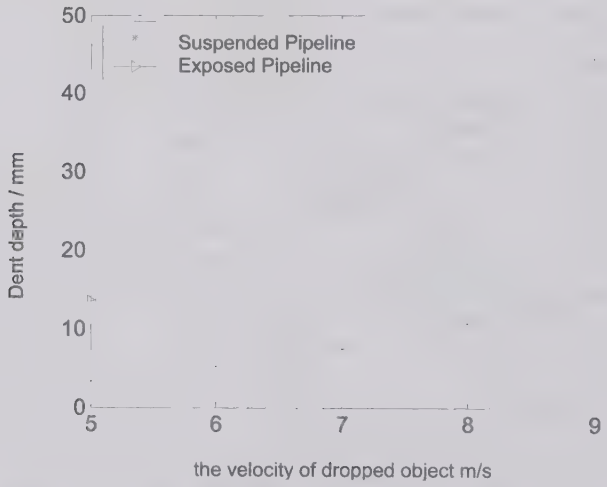

Fig. 7 The dent depths of suspended pipelines compared with the dent depths of bare pipes under different impact velocities

When the velocity is 6 m/s, the dent depth of exposed pipeline is 18.8 mm, and the dent depth of suspended pipeline is 5.2 mm, so the dent depth of exposed pipe is 13.6 mm larger than that of suspended pipeline. When the velocity is 7 m/s, the dent depth of exposed pipeline is 26.3mm, and the dent depth of suspended pipeline is 7.5 mm, so the dent depth of exposed pipe is 18.8 mm larger than that of suspended pipeline. When the velocity is 8 m/s, the dent depth of exposed pipeline is 35.6 mm, and the dent depth of suspended pipeline is 10.7 mm, so the dent depth of exposed pipe is 24.9 mm larger than

that of suspended pipeline. Then conclusions can be drawn that with the increase of impact velocity, dent depth of pipeline gets larger. Under the same impact velocity, the dent depth of suspended pipeline is smaller, which means suspended pipelines can reduce the damage of pipeline to a certain extent, and the larger the impact velocity is, the larger the gap between the two is.

4.2 Impact energy effects

4.2.1 Effect of impact velocity on the damage of suspended pipelines

The effect of different impact velocity on the pipeline damage under the same impact mass is studied in this section. The suspended length is 10 m, and the other parameter is the same with that in chapter 2.1.The results are shown in Fig. 8 and Fig. 9.

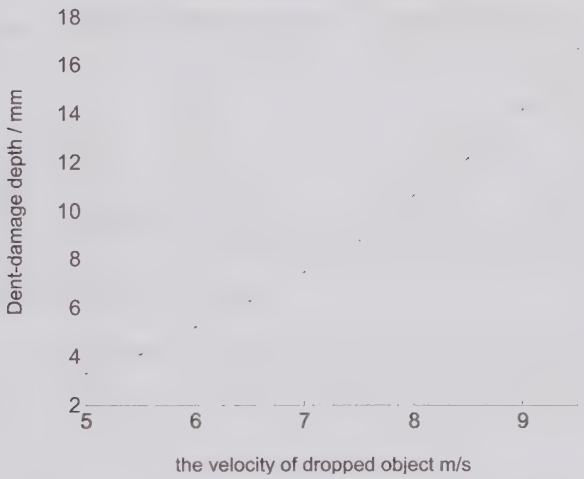

Fig. 8 The dent depths of pipe at different impact velocities

When the velocity is 6 m/s, the dent depth of suspended pipeline is 5.2 mm, and the maximum vibration amplitude is 111.35 mm. When the velocity is 7 m/s, the dent depth of suspended pipeline is 7.5 mm, and the maximum vibration amplitude is 128.91 mm. When the velocity is 9 m/s, the dent depth of suspended pipeline is 16.75 mm, and the maximum vibration amplitude is 175.52 mm. Therefore comes the conclusion: under the same impact mass, with the increase of impact velocity, the dent depth of pipeline gets larger; the damage of pipeline is exacerbated; the vibration amplitude increases and the stress of pipeline becomes larger, which is more prone to cause the yield failure and aggravate the fatigue damage of pipeline.

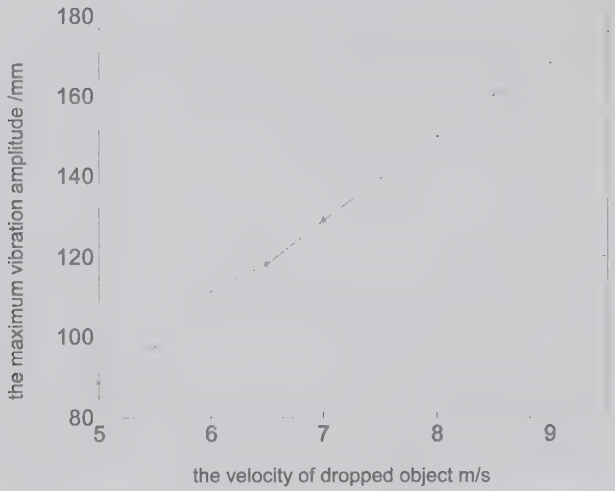

Fig. 9 The vibration amplitude of pipe at different impact velocities

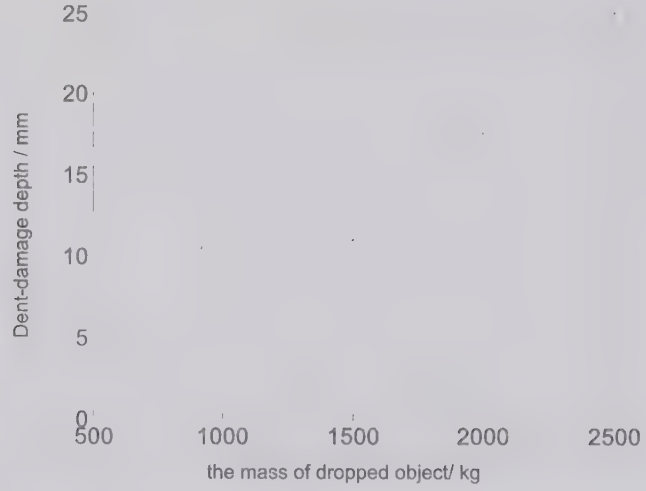

Fig. 10 The dent depths of pipe at different impact mass

4.2.1 Effect of impact mass on the damage of suspended pipeline

The effect of different impact mass on the pipeline's damage under the same impact velocity is studied in this section. The suspended length is 10 m, and the other parameter are the same with chapter 2.1.The results are shown in Fig.10 and Fig.11.

When the mass is 500 Kg, the dent depth of suspended pipeline is 4 mm, and the maximum vibration amplitude is 71.5 mm. When the velocity mass is 1 500 Kg, the dent depth of suspended pipeline is 11mm, and the maximum vibration amplitude is 137.44 mm. When the velocity mass is 2 500 Kg, the dent depth of suspended pipeline is 25 mm, and the maximum vibration amplitude is 163.37 mm. Therefore comes the conclusion: under

the same impact velocity, with the increase of impact mass, the depressed deformation at impact site becomes larger; the damage of pipeline is exacerbated; the vibration amplitude increases and the stress of pipeline gets larger, that is prone to cause the yield failure and aggravate the fatigue damage of pipeline.

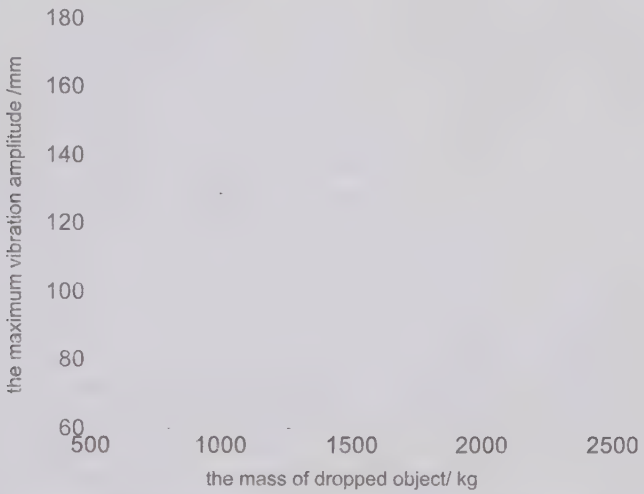

Fig. 11 The vibration amplitude of pipe at different impact mass

4.3 Effect of dropped object's shape

Under the same mass, the shape of the object is changed, and the dent depths of suspended pipelines in different velocities are calculated, and the results are shown in Fig.12.

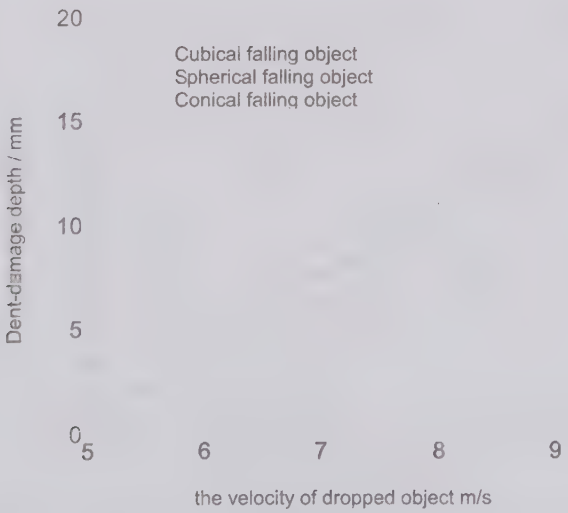

Fig. 12 The influence of the shape of objects on the dent depths

When the velocity is 6m/s, the dent depth of suspended pipeline caused by conical falling object is 6.4 mm, and the dent depth caused by spherical falling object is 5.2 mm, and the dent depth of suspended pipeline caused by cubical falling object is 3.1 mm. When the velocity is 8 m/s, the dent depth of suspended pipeline caused by conical falling object is 11 mm, and the dent depth caused by spherical falling object is 10.7 mm, and the dent depth of suspended pipeline caused by cubical falling object is 6.8 mm. Thus conclusion can be obtained: under the same impact velocity and mass, the dent depth caused by cone falling object is the largest, followed by sphere falling object and that caused by cube falling object is the smallest. This is because the smaller the contact area between the dropped object and suspended pipeline is, the smaller the damage area of suspended pipeline is and the greater the damage depth is.

4.4 Effect of seabed parameters

4.4.1 Effect of elastic shear modulus

Elastic shear modulus refers to the ratio of shear stress and shear strain within the range of elastic deformation proportional limit. The larger the elastic shear modulus is, the stronger the rigidity of the soil is, therefore the more difficult to deform. In the calculation analysis, if elastic shear modulus increases, the buffer action of seabed will be weakened, and the deformation of the pipeline will increase.

When the suspended length is 10 m and impact velocity is 7 m/s, the results in different elastic shear modulus are shown in Fig. 13 and Fig. 14.

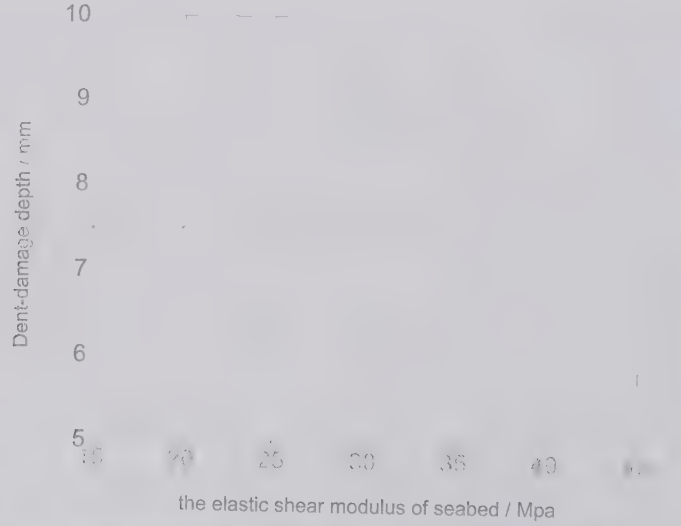

Fig. 13 The influence of elastic shear modulus on the dent depths

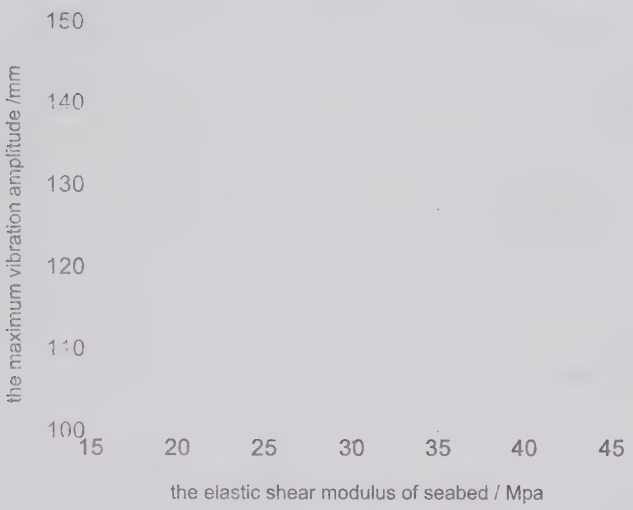

Fig. 14 The influence of elastic shear modulus on the dent depths

When the elastic shear modulus is 15 Mpa, the dent depth of suspended pipeline is 7.48 mm, and the maximum vibration amplitude is 130.41 mm. When the elastic shear modulus is 25 Mpa, the dent depth of suspended pipeline is 7.5 mm, and the maximum vibration amplitude is 128.91 mm. When the elastic shear modulus is 45 Mpa, the dent depth of suspended pipeline is 7.52 mm, and the maximum vibration amplitude is 125.99 mm. Thus, with the increase of elastic shear modulus, the dent depth of pipeline grows slightly, and the maximum amplitude of vibration decreases slightly.

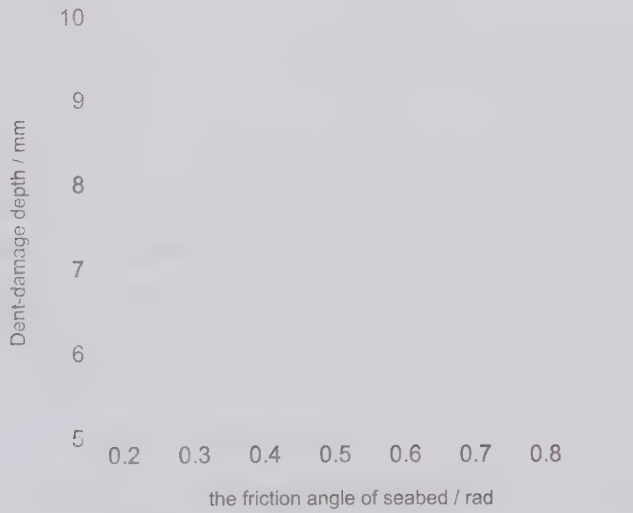

Fig. 15 The influence of internal friction angle on the dent depths

4.4.2 Effect of friction angle

The shear strength refers to the resistance of soil to the shear failure. Soil shear capacity is the essence of the soil strength. The shear strength of soil is composed of two parts: the inner frictional resistance and cohesion. Friction angle depends on the frictional resistance and the chain reaction among the soil particles, and it reflects the friction properties of the soil.

When the suspended length is 10m and the impact velocity is 7 m/s, the results in different friction angles are shown in Fig.15 and Fig.16.

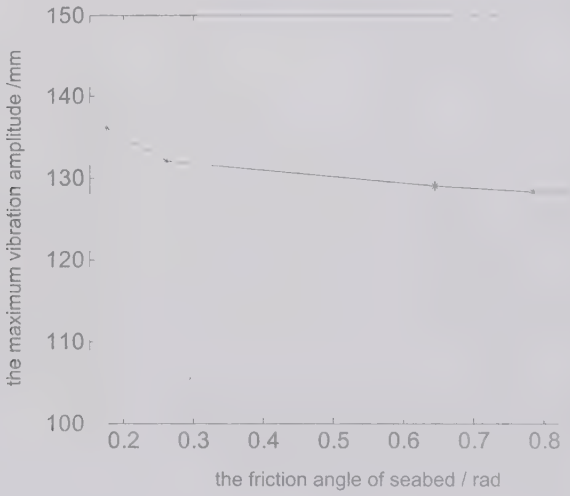

Fig. 16 The influence of internal friction angle on the dent depths

When the friction angle is 0.174 5 rad (10°), the dent depth of suspended pipeline is 7.47 mm, and the maximum vibration amplitude is 136.28 mm. When the friction angle is 0.645 7 rad (37°), the dent depth of suspended pipeline is 7.5 mm, and the maximum vibration amplitude is 128.91 mm. When the friction angle is 0.872 7 rad (50°), the dent depth of suspended pipeline is 7.6mm, and the maximum vibration amplitude is 120.7 mm. Thus, with the increase of friction angle, the dent depth of pipeline grows slightly, the increase is minor, the maximum amplitude of vibration decreases slightly.

4.4.3 Effect of density

When the suspended length is 10 m, impact velocity is 7m/s, and the results in different density are shown in Fig.17 and Fig.18.

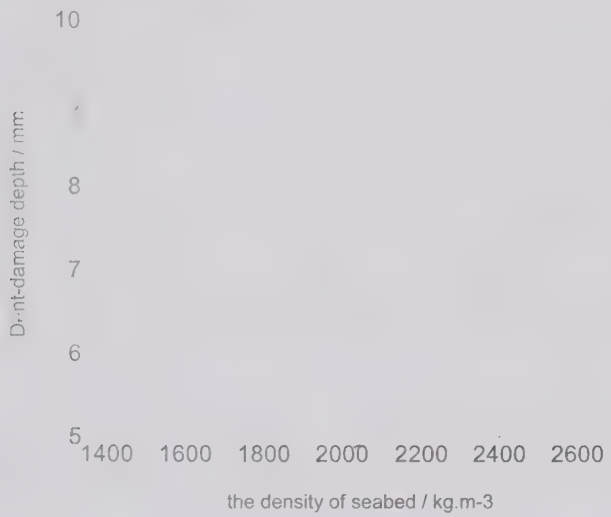

Fig. 17 The influence of mass density on the dent depths

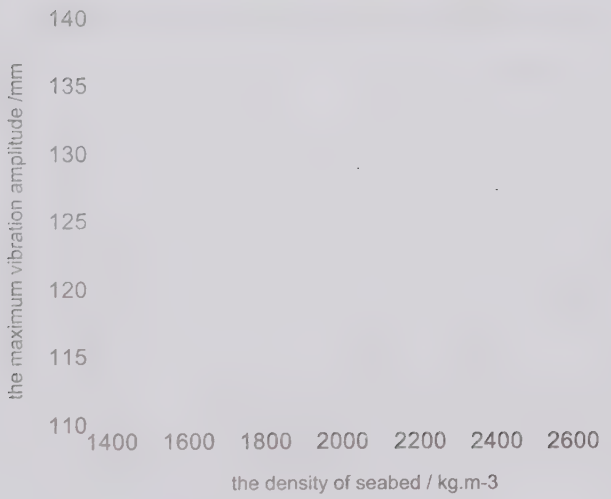

Fig. 18 The influence of mass density on the dent depths

When the density is 1 390 Kg/m^3, the dent depth of suspended pipeline is 7.5 mm, and the maximum vibration amplitude is 132.29 mm. When the density is 2 040 Kg/m^3, the dent depth of suspended pipeline is 7.5 mm, and the maximum vibration amplitude is 128.91 mm. When the density is 2 700 Kg/m^3, the dent depth of suspended pipeline is 7.55 mm, and the maximum vibration amplitude is 126.45 mm. From above analysis, we can conclude that with the increase of density, the dent depth of pipeline is basically unchanged, and the maximum amplitude of vibration decreases slightly, with minor decrease.

5 Conclusions

(1) Based on ANSYS / LS-DYNA dynamics analysis software, this paper builds the pipe-soil collision model. The simulation by this model shows similar results compared with the standard results.

(2) Conclusions are obtained by comparing the dent depth of suspended pipeline with exposed pipeline that under the same impact energy, and the damage depth of suspended pipeline is smaller than that of exposed pipeline, and with the increase of impact energy, the difference grows.

(3) With the increase of impact velocity and impact mass, the dent depth grows, and the maximum amplitude of vibration increases. In the same impact energy situation, the smaller the contact area is, the larger the damage depth is.

(4) With the increase of elastic shear modulus, friction angle and density, the dent depth of pipeline grows slightly, and the maximum amplitude of vibration decreases slightly, but the magnitude of the change is minor.

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基于 LS-DYNA 海底悬空管道受坠物碰撞动力响应分析

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摘 要：[illegible] ANSYS/LS-DYNA 动力学分析软件，采用非线性动力有限元法，对坠物撞击海底管道的过程进行[illegible]的数值模拟得出：相同坠落物能量的情况下，悬空管道的凹陷损伤深度与裸露管道的[illegible]，[illegible]坠落物能量的增加，其差值增大；随着坠落物速度、坠落物质量的增大，管道撞击部位凹[illegible]变形加剧；悬空管道悬空段的最大振动幅值增大；相同坠落物能量的情况下，坠落物与悬空管道的接触面[illegible]，悬空管道凹陷损伤深度越大；海床土体参数（剪切弹性模量、内摩擦角、密度）的变化对悬空管道的凹陷损伤深度及悬空段的最大振动幅值的影响较小。

关键词：悬空管道；碰撞；凹陷深度；动力响应

An emergency decision support system for the marine pollution

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Abstract: The paper introduces the research progress in an emergency decision support system for marine pollution (EDSS) in China seas and elaborates on the possible role of the Neutron Activation Analysis (NAA) method therein. To deal with the increasingly grave situation of offshore pollution, the EDSS for China seas has been researching and developing. Based on the prediction and analysis of the ocean three-dimensional current field, this system makes an inference on the possible path of diffusion and influencing area of marine pollutants and possible location of pollution source, and in combination with the environmentally sensitive information related to the technical integration of GIS, it puts forward the decision, making support for minimizing the hazard caused by pollutants. This system has been operationalized and running for many years on the Bohai and Huanghai seas' Marine Pollutants Prediction and Early-Warning, and it has achieved successful experience for many times in the emergencies of China's coastal pollution accidents. At present, the environmental guarantee system directed against heavy metals and radioactive pollutants is in the experimental stage. As the NAA method is especially applicable to the detection of part of heavy metals and radioactive substances, it is of very important practical value for the new system to realize the monitoring, prediction and early-warning of ocean heavy metals and radioactive pollutants.

Keywords: marine pollution, Neutron Activation Analysis, ocean modeling

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1 Background

In recent years, the economy in the world, especially in the developing countries, has experienced a continued and rapid growth. At the same time, however, with the rapid development of coastal economy and the growth of population, the pollution of water quality in the nearshore areas is being constantly aggravated. The environmental risks as a result of the leakage of hazardous pollutants in the offshore seas of all countries (such as various organic/inorganic pollutants, heavy metals, and man-made radioactive substance) are obviously increasing (Huh and Chen, 1999; Klumpp, et al. 2002; SOA, 2012; Zhang, et al. 2007; Zhijie and Cote, 1991). Once these maritime pollution accidents happen, they will seriously damage the eco-environment of sea and land and bring an immeasurable economic loss.

To sum up, it is an important job to render emergency judgment on the various types of pollutants discovered at sea, including the calculation of how these pollutants diffuse and transfer, and where they have come from. Therefore, it is necessary to strengthen the technological research in the prediction and tracing to the source of maritime pollutant movement, at the same time, to reorganize the environmental resource information and establish an integrated emergency decision support system for marine pollution (EDSS), a technical platform for providing decision-making support for the emergency response and settlement of various pollution incidents at sea (Zou, et al. 2011).

To solve this technical problem, the work of research, development and construction directly against the EDSS for China seas has made initial headway. Meanwhile, the method of the Neutron Activation Analysis (NAA) which could be very useful in EDSS is also introduced in the section 3 of this article. Concretely speaking, it has accomplished prediction and early-warning of part of the pollutants in the Bohai and Huanghai seas in China, and achieved some successful experiences in its application in the past few years (CAI, et al. 2013).

2 The framework of emergency decision support system for marine pollution

The EDSS serves to give the plan for minimizing the hazards of marine pollution. One of its roles is to provide the emergency decision supporting system for marine pollutants. Fig. 1 is a simplified diagram of this system architecture.

For some cases of marine pollution, it is easy to find the moving path of pollutants as

satellite pictures or aero photographs may give adequate evidences, but this is only limited to the pollutants located at the sea surface and in the large quantity. The discharge and change of more pollutants are much more hidden, and they are not limited to the sea surface, which requires advanced technical tools to make routine monitoring of the ocean. Among other things, the NAA method is very well adapted to the monitoring of part of the heavy metals and radioactive substance.

In the meantime, we cannot make an overall and real-time monitoring of all seawater in the ocean and the material transport in the sea is complicated, which has the movement of diffusion and sinking and rising, as well as interaction with the atmosphere, coast and seabed. In this case, the transfer and transformation of pollutants cannot be understood except by means of some researches and other technological tools. Computer simulation is a very good technical means. Based on the basic research of oceanography and the biochemical transformation law of marine pollutants, and the discretization in space of the equation describing the physical and biochemical processes, we may construct the transport model of marine pollutants to model the process of transfer and transformation of marine pollutants by using the computer. But it is not enough to just have the model and computer. To enable the accuracy of its simulation to reach the level of operationalization, large amount of marine monitoring data and maritime experiments are required to make corrections of the multiple parameters of the model. Here, the NAA method can also play a key role.

Generally speaking, the operating principle of this system is first to simulate the historical and future marine environments by using the computer model (Figure 1). When highly hazardous pollutants are found at sea, through our understanding of the property of this type of pollutants and based on the above-mentioned marine environmental data, the source of pollutants and their future path of variations are calculated. And then, in combination with the environmental resource data and emergency resource data, the source of pollution is contained and the plan for minimizing the present pollution hazard is given.

In addition, the EDSS can also provide the decision-making support for how to deploy sewage discharge outlets and for the routine marine environmental management.

3 Potential applications of the neutron activation analysis method in the system

Detection of seawater, suspended matter in the seawater and the concentration of microelement in the submarine sediments may provide an important basis for the

assessment of pollution in the sea and the studies on the law of transfer and transformation of marine pollution elements.

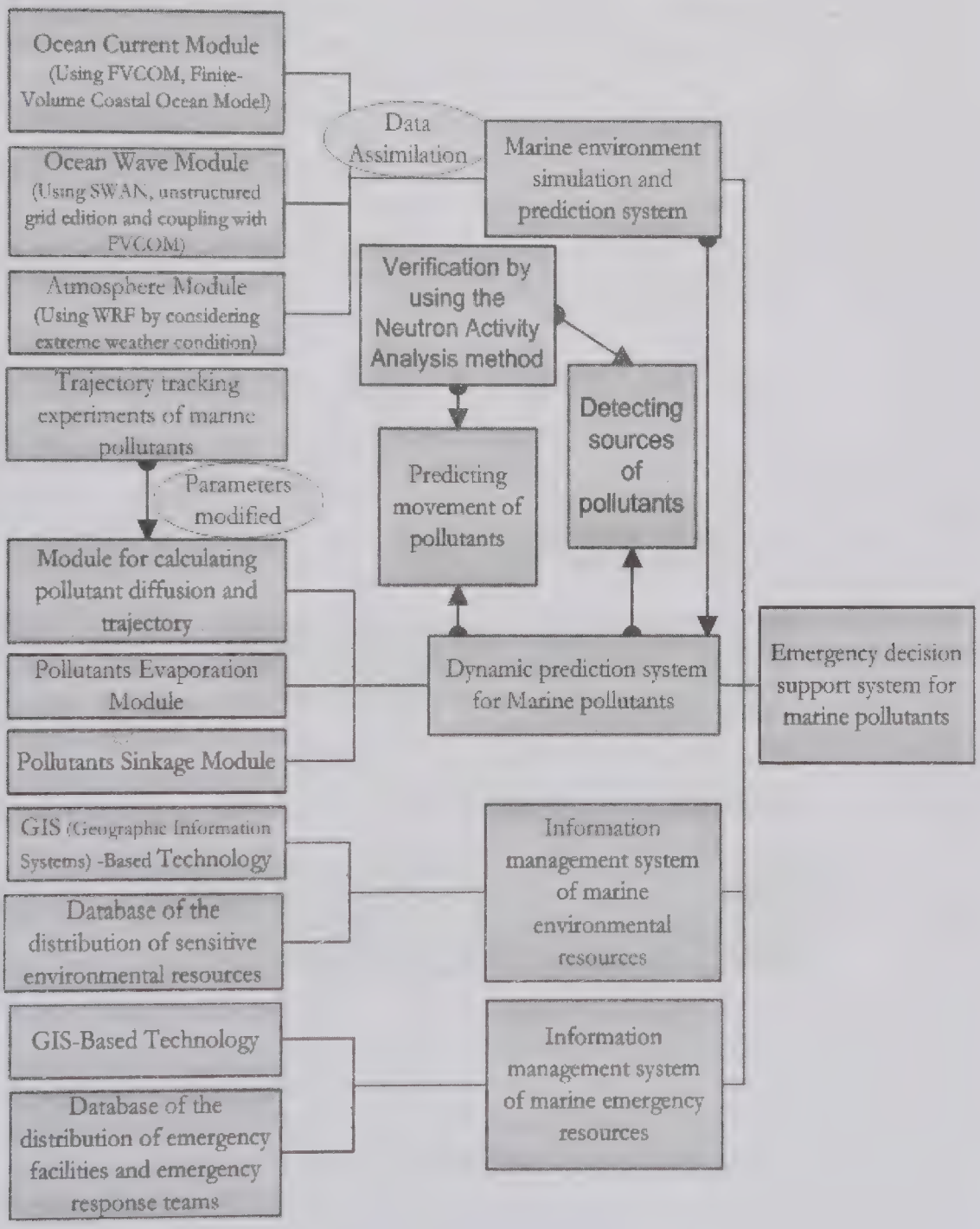

Ocean Current Module
(Using FVCOM, Finite-Volume Coastal Ocean Model)
Ocean Wave Module
(Using SWAN, unstructured grid edition and coupling with FVCOM)
Atmosphere Module
(Using WRF by considering extreme weather condition)
Trajectory tracking experiments of marine pollutants
Parameters modified
Module for calculating pollutant diffusion and trajectory
Pollutants Evaporation Module
Pollutants Sinkage Module
GIS (Geographic Information Systems) -Based Technology
Database of the distribution of sensitive environmental resources
GIS-Based Technology
Database of the distribution of emergency facilities and emergency response teams
Data Assimilation
Marine environment simulation and prediction system
Verification by using the Neutron Activity Analysis method
Predicting movement of pollutants
Detecting sources of pollutants
Dynamic prediction system for Marine pollutants
Emergency decision support system for marine pollutants
Information management system of marine environmental resources
Information management system of marine emergency resources

Fig. 1 Framework of the EDSS

The NAA method has many advantages such as higher sensitivity (especially to Hg, As and Cu) and being easy to correct the effect of matrix,etc. Therefore, the applications of the NAA method in oceanography are very important especially in studying the metal pollutants and trace elements in the marine environment when it is very hard to accurately detect the majority of matter's content and concentration as NAA due to the very low concentration of the matter. This is also the reason why we consider using this method to study marine pollution problems.

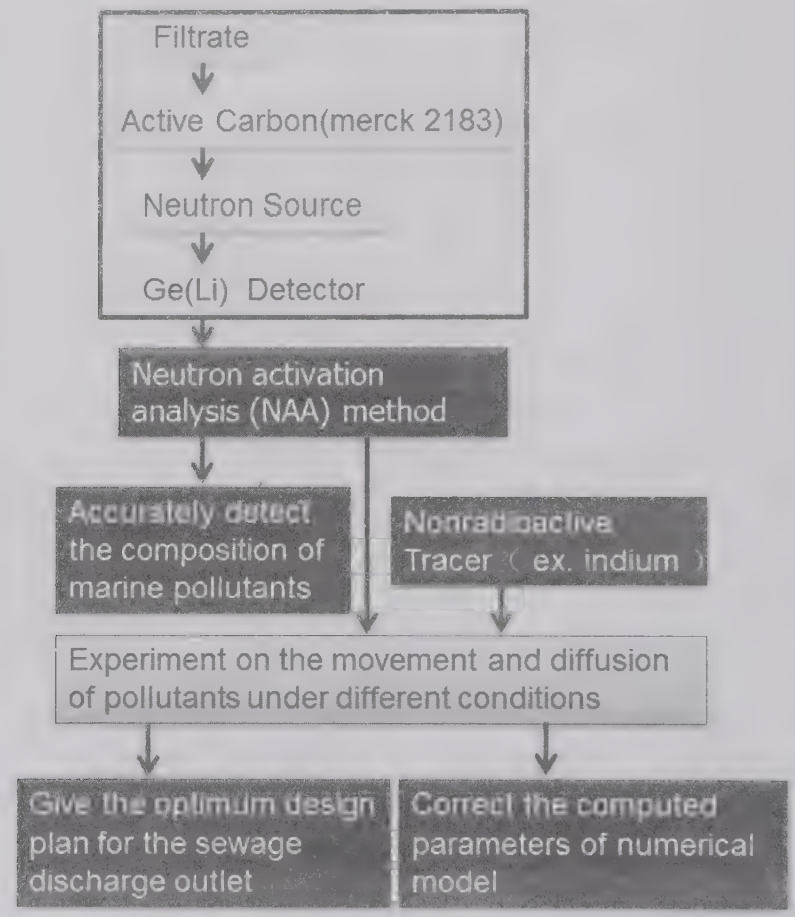

Filtrate
Active Carbon(merck 2183)
Neutron Source
Ge(Li) Detector
Neutron activation analysis (NAA) method
Accurately detect the composition of marine pollutants
Nonradioactive Tracer (ex. indium)
Experiment on the movement and diffusion of pollutants under different conditions
Give the optimum design plan for the sewage discharge outlet
Correct the computed parameters of numerical model

Fig. 2 The role of NAA method in the study of marine pollution

In contrast to other applications of the NAA method, some special treatments need to be made when the NAA method is used to measure the content of elements in the seawater. For example, the activated carbon adsorption and preconcentration method is used to avoid the strong radioactive inference from ^{24}Na (Li, 2004) in the course of implementing the method. However, these technological methods are very mature now.

Fig. 2 shows part of the potential uses of the NAA method in the EDSS. Apart from monitoring, detecting and identifying the marine pollutants, the NAA method may be also used for studying the law of seawater movement and diffusion through the integration with nonradioactive tracers(such as indium).This research approach will not add artificial radioactivity to the environment and the cost is much lower.

These research findings may allow the capacity of marine environment to adapt to various pollutants and directly present suggestions on the way of oceanic discharge of sewage, thus providing decision-making support for local governments. In this connection, Chen (1997) has made a detailed account of the related researches. More importantly, this research may correct the computation parameters of numerical model in the EDSS and improve the accuracy of system computation.

4 The research progress in the EDSS and its applications

The EDSS was researched and developed in the light of such marine pollution incidents as the oil-spill pollution in the Bohai and Huanghai seas, pollution of highly dangerous chemicals, solid refuse and marine ecological disasters (such as red tide) et al. This version of the EDSS has been operational for many years. This system consists of two major parts:

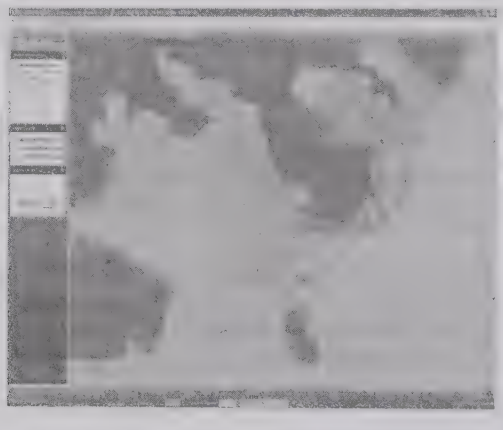
1) The three-dimensional ecological environment numerical model of dynamic and ecological models coupling sea currents, sea wavse and atmosphere etc (Song et al., 2011). It is worth mentioning that the unstructured grid of the sea current model FVCOM (Finite Volume Coastal Ocean Model) selected is quite fit for modeling the areas with more complex geographical features such as harbor, strait, etc. (Chen et al., 2006). The numerical discrete scheme based on finite volume enables the momentum, energy and mass etc. to have better conservation while the wet and dry grid has better adaptability to the conservation. Meanwhile the wet and dry grid has better adaptability to the moving boundary such as flood plain (Chen et al., 2008).

2) Information management system in combination with the environmental resource data and emergency resource data. This system is based on the GIS technical platform and the scientific classification of environmentally sensitive marine resources in China. It accomplishes the electronic dynamic management of the sensitive ocean resources in the major northern cities of China and the jointless coupling with the marine pollutant drift and diffusion model.

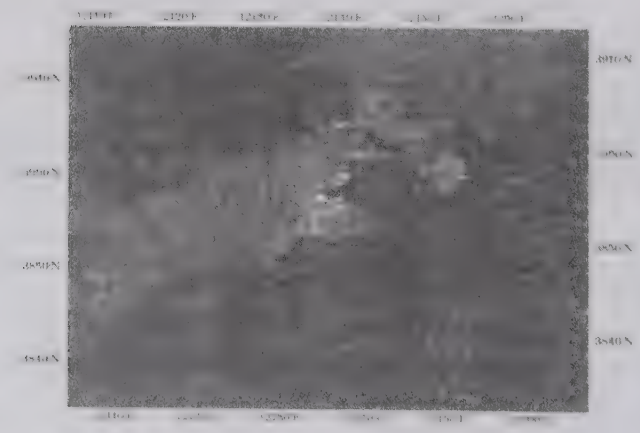
It should be pointed out here that the corresponding pollutants should be established

separately for different pollutants due to greater module differences in physical and chemical properties. This can now make 72 hours' prediction and back tracking to the source of the movement of many grave marine pollutants and it especially has higher accuracy in calculating the variation of the maritime oil-spill pollution condition.

What Fig. 3 presents is the contrast diagram between the simulated results and the satellite observations of the oil-spill distribution in the Dayao Bay and the Dalian Bay 72 hours after (18:00, July 19) the simulation made by the Chinese Department of Maritime Affairs of the Ministry of Communications (Mu and Song, 2011), following the "July 16" major oil-spill accident in the Dalian City (happening at the Beijing Time of 18 hours, July 16, 2010). It can be seen from Fig.3 that the system has very accurately predicted the drift and diffusion of oil-spill and played a better role in the emergency decision-making for the accident.



(a)



(b)

Fig. 3 Comparison between model (a) and satellite observations (b)

5 Perspective in future

The China Marine Pollution Decision Making support system is a new generation of EDSS under the research and development. It has four major improvements in the design.

1) Expanding the system service area to the entire China seas;

2) Strengthening the modeling capacity for the extreme weather processes such as the typhoon;

3) Based on the GIS technology, integrating more information of marine environmental resources and marine emergency resources into the system;

4) Accomplishing the computing capacity for the major heavy metal pollutants and radioactive substances in the ocean.

By now, the first two jobs have been basically done and the integrated management system for the indicators including the integrated management system for the indices has been established for part of the coastal cities, which can determine the priority of protection for sensitive resources in the light of the actual situations of different areas. And these indices include the environmentally sensitive resource raw data, image data, environmental resource sensitivity distribution of emergency equipment bank, distribution of emergency contingent, et al.

Expanding the scope of applications of the marine pollution decision-making support system to all the hazardous heavy metal pollutant matter, the radioactive substances are the major orientation of efforts for the current system development. In view of many advantages of the NAA method mentioned above, using it as a detecting and experimental method for part of the heavy metals and radioactive substances in place of the CAFS (cold atomic fluorescence spectrometry) and the radioactive-tracer method may give greater impetus to this work.

6 Discussion

After a series of disastrous events such as minamata disease occurred since the 1950s, the effect of heavy metal pollution on the offshore environment has drawn a high attention. The distribution of offshore heavy metal pollutions is mainly affected and controlled by the land sewage discharge, hydrodynamic action and sediment granularity (Feng, et al. 2004; Meng, et al. 2008). Considering the rapid growth of coastal industries,

the danger of heavy metal pollution as a result of the industrial waste water leakage or illegal discharge is obviously increasing in the offshore area. In the meantime, the leakage incident of the Japanese Fukushima Nuclear power Station in 2011 has once again reminded us of the fact that, under the conditions of natural calamity or terrorist attack, the radioactive substances leaked in the coastal nuclear power station may bring the serious economic and ecological disasters to the coastal area (Buesseler, et al. 2011; Chang and Zhao, 2012). Therefore, coastal countries need to attach importance to the prediction and early-warning capacity for heavy metals and radioactive pollutants.

Before modeling the transfer and transformation of heavy metals and radioactive pollutants in the ocean, we need first to detect the current state of distribution of heavy metals and radioactive substances (known as the initial field in the numerical model). Based on the initial field information of these pollutants, once marine pollution accidents occur, we can calculate in short time the variations of pollutants in space and time by means of the EDSS so that the government can make in time the reasonable decision on the prevention and control.

As the concentration of heavy metals or radioactive pollutants in the sea water is generally low, the results of the traditional methods of detection have greater errors, while the sensitivity of analysis based on the NAA method may reach 10^{-6}-10^{-14} and, with a good accuracy, the error may be within 1%; Furthermore, the NAA method may analyze and measure several dozen elements in the same one sample simultaneously and so facilitate the detection of such samples as heavy metal pollutants (usually including many elements) (De Soete, et al. 1972; Hogdahi, et al. 1968; Kosta, et al. 1978).

As far as the researches related to marine pollution are concerned, although the NAA is an advanced and mature technology, the only problem is that the neutron source is the rare resource that is generally hard to obtain. Through this paper, we also hope to explicate the urgency of reducing and controlling marine pollution at present and appeal to the surplus neutron source resource in the world to support the marine pollution research work.

Acknowledgements

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海洋环境污染保障系统

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摘 要：本文介绍了一个针对中国海域海洋环境污染保障系统的研究进展，并阐述中子活化分析（Neutron Activation Analysis, NAA）方法在其中的可能作用。该系统基于对海洋三维流场的预报与分析，对海洋污染物可能的扩散路径与影响区域、污染源头的可能位置进行推测，并结合 GIS 技术整合相关的环境敏感信息，为如何使污染物造成的危害降到最低给出决策支持。基于该系统技术的渤黄海海洋污染物预测预警系统已经实现业务化运行多年，并在中国沿海污染事故应急中多次获得成功的经验。目前，针对重金属与放射性污染物的环境保障系统正处于理论实验阶段，由于 NAA 方法特别适合用于对部分重金属及放射性物质的检测，因此 NAA 方法对实现海洋重金属及放射性污染物的监测及预测预警具有非常重要的实用价值。

关键词：海洋污染；中子活化分析；海洋模型

Energy-based marine ecological footprint in Shandong province, China

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Abstract: An energy-based ecological footprint model was set up to monitor the sustainable development status of a specific marine system. This model used unit energy value and energy density to convert the consumption into ecological productive areas. It can reflect the utilization degree of resources in the regional development. Then, the quantitative analysis of sustainable development was done by comparing the size of the areas. We defined the concept of energy-based ecological footprint of marine and built energy-based ecological footprint model of marine. Then we applied this model to marine ecological system of Shandong province to evaluate its sustainable development statue. The results showed that the energy-based marine ecological footprint of the marine ecological system in Shandong province was 1.74 × 106 hm^2 in 2010, and the energy-based ecological carrying capacity of this area was 1.60×107 hm^2 per capita. Thus, the marine ecological system of Shandong province has strong sustainability.

Keywords: marine system; ecological carrying capacity; ecological footprint; energy theory; Shandong province

1 Introduction

Quantitative analysis of the sustainable development of marine economy has become a research direction of many scholars (HAN Zenglin et al., 2003; DI Qianbin et al., 2009; SHAO Guilan et al., 2011; LI Fuxing et al., 2013) in the study of sustainable development. The ecological footprint model (Rees W E, 1992) provides a new theory and method for the quantitative study on the sustainable development of marine economy.

Many researchers have applied the traditional (XU Zhongmin et al., 2003; WEI Ming et al., 2006; YANG Tianzi et al., 2009) or modified ecological footprint model (SUI Chunhua et al., 2006; YANG Haibo et al., 2009; YANG Haizhen et al.,2010) to measure the

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sustainable development status of different regions. The energy model was induced in the early 1990s (LAN Shengfang et al., 2001, 2002). The domestic scholars (WANG Jianyuan et al., 2007; ZHAO Zhiqiang et al., 2008, 2009; LIU Miao et al., 2008) use the improved energy-based ecological footprint to study the energy ecological capacity and energy ecological footprint of different regions. The improved energy-based ecological footprint is the combination of the traditional ecological footprint model and energy theory. In the calculation of energy-based carrying capacity, most of the researches use global average energy density (ZHANG Fangyi et al., 2006; SUI Chunfeng et al., 2008), but in the calculation of energy-based ecological footprint, they usually use regional energy density. There are many scholars who have improved energy-based ecological footprint method from different angles. For example, Jin Dan and Bian Zhengfu calculated regional energy density with the total three main kinds of energies in the earth's biosphere cycle in specific regions, and they used the same energy density to calculate the energy-based carrying capacity and energy-based ecological footprint (JIN Dan et al., 2010); Zhao Zhiqiang and other researchers defined the renewable resources of the input system as potential ecological carrying capacity, and product output and import and export and labour services were all included in the scope of ecological carrying capacity (ZHAO Zhiqiang et al., 2008); Liu Miao and other researchers treated all the available renewable energy as total energy of ecological carrying capacity. And they used regional energy density, the ratio of this energy and the study area, to calculate ecological carrying capacity. These studies on the regional economy from different angles provide a scientific basis for regional sustainable development (YANG Shan et al, 2011; ZHAO Meixia et al., 2011). Ecological footprint model was applied to the marine sustainable development by domestic scholars. However, study on the regional marine economy is not common. Energy-based ecological footprint model overcomes partial ecological characteristics of ecological footprint model (GU Kangkang et al., 2009). And energy-based ecological footprint is more realistic to reflect the status of regional sustainable development for its evaluation perspective of ecological environment, social and economic development. In this paper, the model is applied to the marine ecosystem based on the feasibility of energy theory and ecological footprint model in the evaluation of sustainable development. Also we innovatively build energy-based marine ecological footprint and analyze the sustainable development of regional marine economy taking Shandong as an example.

2 Study areas

The marine area of Shandong is 1.595×10^5 km^2. It is located in Bohai Sea and Yellow Sea, with the Penglai angle for the community, to the west of Bohai Sea, the east of Yellow

Sea. The total length of the coastline is 3 345 km, to the north of Zhangweixin river estuary (38°15′43.77″N), the south of Xiuzhen river estuary (35°04′45″N). Shandong coast has warm temperate monsoon climate, winter prevailing northerly winds, and summer prevailing southerly winds. The average annual wind speed is of 7.1 - 7.5 m/s, with the average annual rainfall between 580 - 916 mm, sunshine hours of 2300~2900 hr. Coastal tide is irregular semidiurnal tide and regular semidiurnal tide. Offshore wind energy, tidal energy, wave energy, and other marine energy resources which can be developed are abundant.

Marine economy develops well in Shandong province. The marine GDP has been in the forefront of the country, which reached 7 074.5 billion yuan in 2010, accounting for 17.9% of the total value in China. The three marine industries accounted for 6.3%, 50.2% and 43.5%. The marine fishery yield was 631 million tons (distant fishery 1.5×10^5 t), and sea salt yield was 2.273×10^7 tons, ranking first in the country. Marine fishery, marine industry, marine medicine, marine electric industry, coastal tourism and marine transportation industry increased by 16.4%,36.0%,68.9%,5.6%,22.7% and 8.0%, respectively, comparing with the previous year. The extent of the marine resource is rich and economy continues grow.

3 Data sources and processing

3.1 Data sources and processing

In this paper, the basic renewable resources data derived from "Marine function zoning in Shandong Province (2011 - 2020)". The consumption data of marine resources were from "Chinese Marine Statistical Yearbook (2001 - 2011)", "Chinese Marine Yearbook 2011", "Shandong Statistical Yearbook 2011" and "National economy and society developed statistical bulletin 2010 of Shandong Province". Data calculation and mapping were done with EXCEL and WORD respectively.

3.2 Marine energy-based ecological footprint model

3.2.1 The concept of marine energy-based ecological footprint

Carl Folke and other scholars (Folke C, et al., 1991, 1998) defined the marine energy-based ecological footprint as the surface area of the marine ecological system occupied by human beings that meet their needs and services. Warren-Rhodes and other scholars (Warren-Rhodes K et al., 2003) gave the numeric expression of marine ecological footprint: MEF=SC/AS. SC means the marine area we need to product certain consumption; AS means regional actual marine area, and we can judge the regional

ecological deficit and surplus through the value of MEF. Domestic scholars such as Chen Chengzhong (Chen Chengzhong et al., 2008) put forward the concepts of marine footprint and marine biology carrying capacity. He defined marine footprint as the catches of marine living resources unit waters and marine biology carrying capacity as the ability unit waters to supply the human biological resources. Also he simulated the maximum sustainable marine footprint by using nonlinear science theory.

Tab. 1 The raw data of natural marine resources in Shandong from 2000 to 2010

Years	Marine fishing output / kg	Marine culture output / kg	Marine oil output / kg	Marine natural gas output / m^3	Sea salt output / g
2000	3.08E+09	2.87E+09	2.18E+09	3.76E+07	1.050E+13
2001	2.78E+09	3.05E+09	2.14E+09	1.56E+08	8.700E+12
2002	2.72E+09	3.26E+09	2.12E+09	1.69E+08	1.240E+13
2003	2.68E+09	3.36E+09	2.01E+09	1.51E+08	1.010E+13
2004	2.70E+09	3.42E+09	2.14E+09	1.88E+08	1.130E+13
2005	2.68E+09	3.58E+09	2.12E+09	1.64E+08	1.610E+13
2006	2.57E+09	3.74E+09	2.16E+09	1.39E+08	1.950E+13
2007	2.45E+09	3.54E+09	2.26E+09	1.56E+08	2.070E+13
2008	2.48E+09	3.61E+09	2.32E+09	1.68E+08	2.120E+13
2009	2.37E+09	3.81E+09	2.4E+09	1.62E+08	2.410E+13
2010	2.35E+09	3.96E+09	2.46E+09	1.29E+08	2.270E+13

Note: the data in this table derived from "Chinese Marine Statistical Yearbook (2001-2011)".

Based on the definition of the marine ecological footprint and the energy theory created by H T Odum, we transformed the energy of ecological or ecological economic system that can't be directly compared into solar energy through solar transformity. In this paper, we defined the marine energy-based ecological footprint as the sea surface area occupied by the energy consumed by human to meet their need of seafood. We used solar transformity and marine energy density to complete the conversion. We defined the marine energy-based carrying capacity as the energy of renewable resources of marine ecosystem.

Because of the flow of sea water, complexity of marine environment and the three-dimensional marine development, study of marine economy is more complex than land economy. In this paper, the energy-based ecological footprint model is applied to the study of marine economy, mainly based on the following consideration: (1) each coastal area has its regional characteristics, such as its natural marine resources, marine economic development level and social conditions. From the aspect of scientific research of regional economy, we can divide regional marine into a relatively independent economic research unit based on their different development. (2) The natural marine energy resources are based on particular area location and climate conditions, and marine mineral resources are based on marine biogeochemical cycle of long-term accumulation, so they won't change in the short term. Marine biological resources and marine productivity are easily affected by natural disaster and man-made disaster in a short time. But based on the strong self-regulatory function of marine ecosystem, it will not change in a certain period. (3) the jurisdiction areas of marine resources yield and the utilization of marine energy are taken as ecological footprint index. The consumption of resources outside the range is external input energy. Figure 1 is energy flow diagram of marine resources in particular sea area.

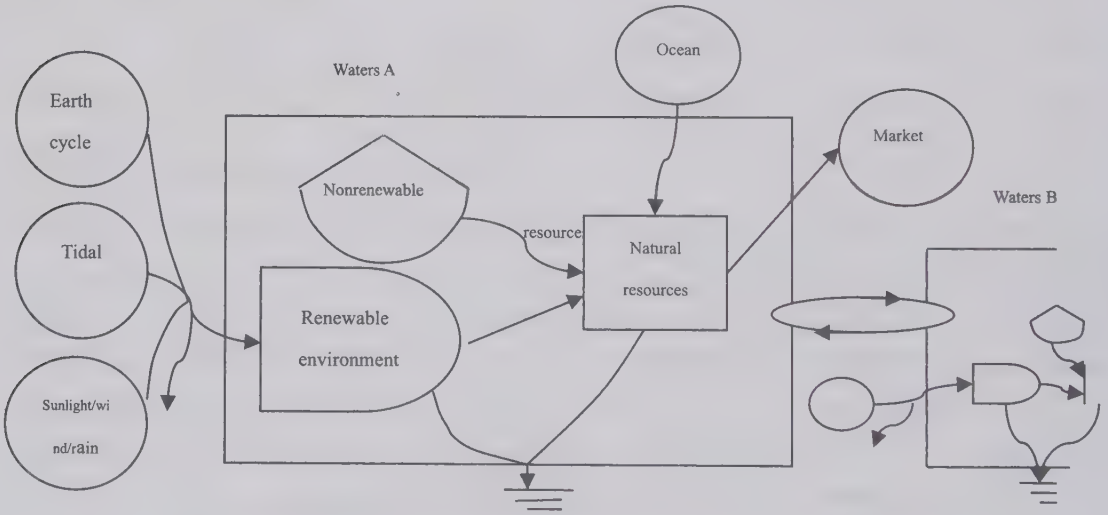

Fig. 1 Energy flow diagram of marine resources in particular sea area

3.2.2 Natural resources of marine ecosystem energy calculation

The marine ecosystem of renewable natural resources includes solar radiation energy, wind energy, rain chemical energy, wave energy, tidal energy, temperature difference energy, salinity gradient and the earth rotation energy. The total energy is expressed as Er. Nonrenewable energy resources, including offshore oil and marine natural gas, are expressed as En. The energy of natural resources (sej) is expressed as

the effective energy (J) × transformity (sej/J).

3.2.3 The marine energy density calculation

Because the solar radiation energy, wind energy, rain chemical energy, wave energy, temperature difference energy and salinity gradient are produced by solar radiation, and the tidal energy and tidal current energy are caused by the sun and the moon on the earth's gravitation, we only take the maximum value to calculate the energy density. The marine energy density formula is calculated as follows:

$$D = \frac{Er_{[maxA,maxB,C]}}{S} \tag{1}$$

In the formula, D represents marine energy density; *Er[maxA, maxB, C]* represents the maximum of solar radiation energy, wind energy, rain chemical energy, wave energy, temperature difference energy, salinity gradient, and the maximum of tidal energy and tidal current energy and the earth rotation energy; S represents the marine area of study area.

3.2.4 Marine energy / currency ratio (sej/$) calculation

For the human consumption of natural resources and environment can be measured by energy, the actual circulating monetary purchasing power of economic system can be measured by the monetary unit purchases of energy. So the resources and environment consumption expressed in the monetary can be converted to energy through energy/ currency ratio. Then we can calculate the energy-based ecological footprint. According to Lan Shengfang (2002), we derived the marine energy/ currency ratio through national energy/ currency ratio:

$$national\ emergy\ /\ currency\ ratio = \frac{tle\ country's\ annual\ total\ emergy\ input}{tle\ currency\ circulation\ tlat\ year} \tag{2}$$

$$marine\ emergy\ /\ currency\ ratio = \frac{Er + Enr + Eo}{gross\ ocean\ production} \tag{3}$$

In the formula (2), the country's annual total energy input including energy of renewable resources, nonrenewable resources and imported goods. In the formula (3), Er represents the total energy input of renewable natural resources in the study area; Ero represents the total energy input of nonrenewable natural resources in the study area; Eo represents the outside resource input energy. Marine energy / currency ratio represents the unit gross ocean production energy.

3.2.5 Marine energy ecological carrying capacity calculation

The marine energy ecological carrying capacity formula is calculated as follows:

$$\mathbf{MEEC} = \frac{Er}{D} \tag{4}$$

In the formula, MEEC represents marine energy carrying capacity, and Er represents available renewable natural resources of marine ecosystem. And $\mathbf{I}$ represents marine energy density.

3.2.6 Marine energy-based ecological footprint

The marine energy-based ecological footprint formula is calculated as follows:

$$\mathbf{MEEF} = \frac{Ec}{D} \tag{5}$$

In the formula, MEEF represents marine energy-based footprint; Ec represents the consumption of marine resource total energy, marine ecological footprint consumption project including marine fisheries (marine fishing and aquaculture), sea salt, crude oil, marine natural gas, marine chemical, marine medicine, marine electric power, comprehensive utilization of seawater, marine engineering construction and waste water, solid waste discharged into the ocean. Because marine chemical industry includes such production activities as sea salt chemical industry, marine chemical industry, and marine petroleum chemical industry, we only take the raw yield data from marine resources to avoid repeated computation. Marine biological medicine is made of sea products, so we only take the marine fishing and aquaculture data to calculate ecological footprint. $\mathbf{I}$ represents marine energy density.

4 Energy-based ecological footprint analysis of marine ecosystem in Shandong

The output of marine natural resources not only supplies local consumption of Shandong, but also domestic and foreign parts. And there is no specific statistical data about the outside consumption of marine resources in Shandong. Therefore, we assess the marine ecosystem by calculating total marine energy carrying capacity and total energy-based ecological footprint.

Tab. 2 is about marine renewable resources in Shandong province. Based on the global energy base 9.26×10^{24} sej/yr (Campbell D E et al., 2004; Campbell D E, 2000), the

total energy carrying capacity of marine ecosystem in Shandong is 1.60×10^7 hm^2 according to formula (4). And according to formula (1), the energy density of marine ecosystem in Shandong is 1.24×10^{17} sej/hm^2. The calculation of marine energy carrying capacity only considers five kinds of renewable resources total energy of the marine ecosystem. Because of the data missing such as ocean current energy, wave energy, temperature difference energy and salinity gradient, the calculated values of marine energy carrying capacity is too small.

Tab. 3 is about energy-based ecological footprints in Shandong province. According to formula (5), the total energy-based ecological footprint in 2010 was 1.74×10^6 hm^2. The marine ecological footprint index chosen by us is that their consumption will cause certain ecological impact. The nonrenewable resource items we used to calculate marine energy/ currency ratio include offshore oil, marine natural gas and marine mining.

Tab. 2 Marine renewable resources energy in Shandong province in 2010

Item	Basic data (J)	Transformity (sej/J)	Energy (sej)
Sunlight	1.22E+21	1	1.22E+21
Marine wind	1.21E+21	1470	1.78E+24
Rain chemical energy	5.36E+17	18100	9.70E+21
Tidal energy	7.74E+18	24300	1.88E+23
Earth cycle	1.595E+17	33700	5.38E+21
Total	—	—	1.99E+24
Total energy carrying capacity (hm^2)	—	—	1.60E+07

Note: the transformity reference Campbell D E, 2000, 2004.

Deep-sea fishing of aquatic products (1.64×10^{21} sej) is included in external input energy. And the marine energy/ currency ratio of Shandong is 1.93×10^{13} sej/$.

Fig. 2 is about energy-based ecological footprint of marine natural resources in Shandong province from 2000 to 2010, including marine fishing, marine aquaculture, marine oil, marine natural gas and sea salt. The ecological footprint of marine aquaculture continued to rise from 2000 to 2010, but the ecological footprint of marine fishing was heading downward. The ecological footprint of sea salt presented the biggest rise, but the ecological footprint of energy resources didn't have too much change.

Tab. 3 Energy-based ecological footprints in Shandong province in 2010

Item	Basic data (J /t /$)	Transformity (sej/J)	Energy (sej)	Energy-based ecological footprint(hm^2)
Marine fishing	2.59E+19	1.96E+06	2.58E+22	2.08E+05
Marine aquaculture	4.36E+19	1.96E+06	4.34E+22	3.50E+05
Marine oil	1.03E+17	5.3E+04	5.46E+21	4.41E+04
Marine natural gas	5.02E+15	4.8E+04	2.41E+20	1.94E+03
Sea salt(t)	2.27E+09	1.0E+09(sej/g)	2.27E+22	1.83E+05
Marine mining(t)	4.26E+06	1.0E+09(sej/g)	4.26E+21	3.43E+04
Industrial wastewater（direct emission）	4.70E+14	8.6E+05	4.04E+20	3.26E+03
Marine electricity($)	3.91E+08	1.9E+13(sej/$)	7.43E+21	6.00E+04
Marine engineering construction($)	5.55E+09	1.9E+13(sej/$)	1.05E+23	8.51E+05
Total energy-based ecological footprint	—	—	—	1.74E+06

Note: the transformity reference Lan Shengfang, "Energy analysis of ecological economic system", 2002.

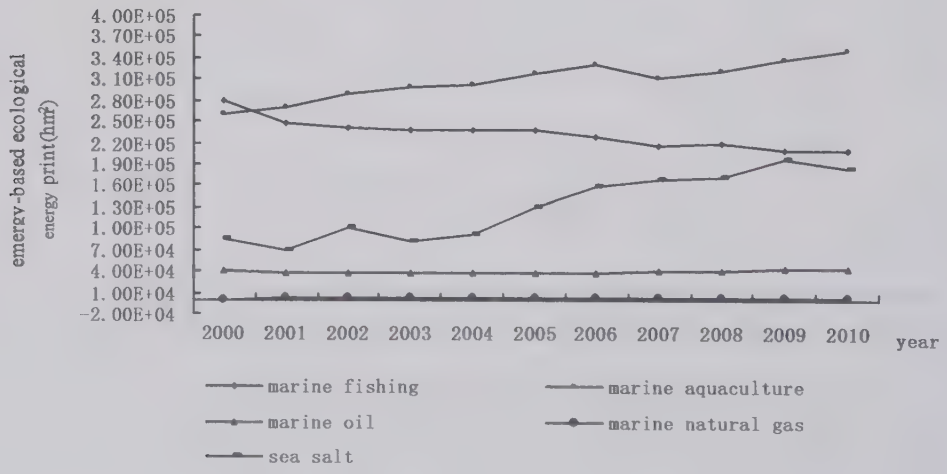

Fig. 2 Energy theory -based ecological footprint of marine natural resources in Shandong province from 2000 to 2010

5 Discussion and conclusion

(1) The marine ecosystem of Shandong province is in the ecological surplus.

According to marine energy-based ecological footprint, the total energy carrying capacity (1.60×10^7 hm^2) is larger than the total energy-based ecological footprint (1.74×10^6 hm^2), so the marine ecosystem of Shandong province is in the ecological surplus. The reasons are as follows: 1) Because of the unique geographical conditions and natural environment, the sea area in Shandong has abundant renewable energy resources. So the available energy of marine ecosystem in Shandong is relatively large and it has strong energy ecological carrying capacity (marine energy density of Shandong is 1.24×10^{17} sej/hm^2, 400 times higher than the global average energy density calculated by Odum and other scholars , which is 3.104×10^{14} sej/hm^2 (Odum H T, 1996)). 2) Energy reserves of natural resources in regional ecosystem energy flow are far less than the energy reserves of renewable energy resources. Although marine fishery yield in Shandong province has been high, but energy of marine electricity (wind power, tidal power) is 7.43×10^{21} sej in 2010, only accounting for 3.95% of tidal energy, we can see that marine renewable energy resource utilization is very low. From Fig. 2, we can see that the proportion and the growth of energy-based ecological footprint of offshore oil and marine natural gas are very small. Marine energy-based ecological footprint is far less than the energy ecological carrying capacity. The marine ecosystem is in the ecological surplus.

(2) The marine energy-based ecological footprint of second industry is bigger than that of the first industry in Shandong province.

Tab. 3 shows that the energy-based ecological footprint of marine engineering construction industry, accounting for 49.02% of the total energy-based ecological footprint, is larger than that of the marine natural resources. Because of the rapid development of third marine industry in recent years, such as marine transportation, marine tourism and marine scientific research and educational services, and as the infrastructure of marine industry, marine engineering construction will have continuous growth. As the growing of marine engineering construction industry, the space area it occupies increases as well. The occupied area and its adjacent waters ecosystem balance will be destroyed, resulting in marine natural resources decline, and even some marine species are on the verge of extinction. Therefore, marine engineering construction brings ecological damage in many aspects. We can see from Fig. 2, the energy-based ecological footprint of offshore oil and marine natural gas has increased slightly, and the energy-based ecological footprint of sea salt has the largest increase. According to “China marine statistical yearbook 2001 - 2011”,

the production of sea salt in Shandong province accounted for less than 50% of the national production. And it increased from 56.9% to 69.2% from 2005 to 2010. The energy –based ecological footprint of sea salt in Shandong is bigger, also it can meet the demand of sea salt in most parts of the country. From Tab. 3 we can see the energy-based ecological footprint of wastewater disposing into the sea with direct emissions of 3 260 hm^2. So the industrial wastewater has brought harm to the marine ecological system to some extent and consumed part of energy of the system. All in all, the second marine industrial energy consumption is bigger than the first industry, so is the energy-based ecological footprint.

(3) The energy-based ecological footprint of marine aquaculture has increased slightly, but the internal industrial structure changed greatly.

Fig. 2 shows that the energy-based ecological footprint of marine fishing has decreased by 15.4% and the energy-based ecological footprint of marine aquaculture has increased by 29.9% from 2000 to 2010. Marine aquaculture beyond marine fishing industry has become the pillar industry of marine fishery in Shandong province. The reasons are as follows: 1) Increase of human marine consumption leads to marine over fishing, water pollution, the destruction of the marine life chain, decrease in the biological number and species, marine fishery resources declining and marine fishing will decrease. According to the statistics from Shandong Province Oceanic and Fishery Department, there are 47 main fishery species in Shandong province coastal area, and 27 kinds of them have been excessively used, and 6 kinds of them have been in severe recession. 2) Shandong province is committed to the development of modern aquaculture technology. From the foundation of Marine Aquaculture Research Institute of Shandong in 1950 to the foundation of Modern Aquaculture Industry Technology Innovation Strategic Alliance, and from basic theory to technology application research, the technical level of aquaculture has developed and the industry scale continues to expand. As the marine aquaculture production increases year by year, the output of marine aquatic products remains stable.

In this study, we apply the energy-based ecological footprint to the marine ecosystem, in order to provide effective theory and method for the research of sustainable development of marine economy. However, the complexity of marine ecosystem and the error and loss of marine statistical data are the obstacles of marine ecological footprint study. The using of energy-based ecological footprint to evaluate the status of sustainable development of marine economy still needs further improvement. But the marine energy-based ecological footprint will be a more reliable evaluation of sustainable development tools underlying continuous improvement. Also it can provide scientific and reasonable basis for the specific regional, national and global sustainable development of

marine economy.

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基于能值的山东省海洋生态足迹研究

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摘 要：能值-生态足迹模型是基于能值理论基础，结合生态足迹模型，运用区域能值密度将各项消费项目转换为可以直接相加的生物生产性面积，并以此来反映区域发展对区域环境资源的利用程度，衡量和评价区域海洋经济的可持续发展状况。本研究将能值-生态足迹模型应用到区域海洋生态系统中，对海洋能值-生态足迹概念进行了界定，构建了海洋能值-生态足迹模型，并以山东省海洋生态系统为例进行了实证研究。结果表明，2010 年山东省海洋生态系统总能值-生态足迹为 1.74×106 hm^2，海洋生态系统总能值-生态承载力为 1.60×107 hm^2，处于生态盈余状态，反映出山东海洋经济具有较强的可持续性。

关键词：海洋系统；生态承载力；生态足迹；能值；山东省

Study on effects and treatment of ocean oil pollution

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Abstract: Because of the special physico-chemical properties and toxicity of oil in ocean, it causes the acute and chronic toxicity in marine life, through food chain comes into human body, has a serious harm on human's health. This test analysis influence of oil pollution in ocean, provides theoretical guidance of governing.

Keywords: oil pollution, marine ecology, influence

Marine oil pollution lasted for a long time, it's difficult to decompose in nature, it causes great harm to marine biological resources and ecological environment. The main treatment methods of oil pollution is physical methods, chemical methods and biological methods. However, due to contamination with ocean current, scope of pollution was not fixed, petroleum hydrocarbons was hard decomposed, that all brought great challenges to marine oil pollution control.

1 The source of ocean oil and pollution situation

1.1 The source of ocean oil

Currently, there are two input type of ocean oil pollution, sudden and lengthy long-term input. Sudden input contains tanker accidents, offshore oil exploration and oily wastewater discharge; long-term input contains port and ship operation oily wastewater discharge, discharge offshore oil wastewater, natural undersea leak and oily sea sediments spilled, industrial and residential wastewater discharge, oily waste gas settlement and so on[1]. In addition, frequent oil marine transportation and port handing also increase the probability of oil spilled; large-scale tankers also adds the possibility of a major oil pollution, increased the difficulty of handing pollution [2, 3].

1.2 Current oil pollution situation

At present, two-thirds of the world's oil needs transport by sea, several of the world's

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busiest transport routes such as the North Atlantic, the Suez Canal, the Cape of Good Hope and so on, all became the most polluted areas. There are more than 7000 tankers transport oil, because of the lower operating costs and high economic efficiency. So thank to modern technology, oil tanker construction has grown faster, volume of large oil tankers can reach more than 200000 tons, but if the huge tankers crashed, oil spilled into sea, causing serious marine oil pollution [4].

In March, 1978, "Moge-Cadiz" struck a rock, more than 200 thousands of oil spilled into the sea, caused more than 20 thousands seabirds, 9 thousand tons of oyster and millions of seafish, urchins and other benthic animals died. Persian Gulf War spilled about 8 million barrels of oil in 1991, becoming the worst in human oil pollution history. A 300-ton foreign oil tanker caused oil pipeline explosion oil spilled in Xingang Dalin in 1991.

"deep level" oil platform which belongs to BP occurred breakdown and explosion in Gulf of Mexico in April 2010, it is estimated 12 000 - 100 000 barrels of crude oil a day are leaking into the Gulf of Mexico, with at least 25 000 square kilometers of the sea was covered with oil. In June, 2011, the US company ConocoPhillips occurred oil spilling in 19-3 Penglai China, about 700 barrels of oil and 2 500 barrels of mineral oil the drilling mud spill in Bohai Bay and the sea bed, caused a total of more than 5 500 square kilometers the sea water pollution. According to the State Oceanic Administration investigation, by the oil spilling incident, in Hebei, Shandong, Tianjin and other cities, many seafood farmers and fishermen may suffer loss up to 10 billion yuan.

2 Mechanism of oil pollution

According to estimates, 1 t of oil in ocean will cause 12 square meters of sea covered with oil slick. Oil main harm to marine ecology environment mainly following these areas: oil slick prevented the exchange between atmosphere and seawater, reduced capacity solar radiation penetration into sea. impact marine phytoplankton on photosynthesis, caused the death of algae and phytoplankton, thus reduced food in water. Water soluble oil have direct toxic effects on fish, caused fish poisoned even die; oil slick was attached to fish gills, it makes a breathing problem with fish. Those all great harm for fish survival, growth of Seabirds will lost ability of flight and swim because of the oil slick on its surface; settled oil covered sediment, damaged benthic ecological, interfered with normal growth and reproduction of benthic organisms; oil also has influence on smell of fish, or come into fish, shrimp, shellfish, algae with chain of food, affected their economic value, endangered people's health.

3 Influence on marine ecological environment by oil pollution

3.1 Influence on marine ecological environment by oil pollution

Multidisciplinary studies show that petroleum hydrocarbon contamination serious harm to the marine environment ecosystem. Different kinds of marine organisms at different stages of growth have varies response to different hydrocarbons, and damaged ecosystems might be slowly recovering, it takes several years to decades [5]. Oil slick covered on sea, prevented exchange of oxygen carbon dioxide and other gases, resulted in acid-base balance in ocean, undermined ocean regulation for greenhouse effect [6,7]. Oil slick prevented sunshine into ocean, reduced water temperature, have bad effect on marine plants photosynthesis. Seawater dissolved hydrocarbons and emulsified oil can clog the pores of plant respiration, or invasive marine plants, destroy chlorophyll, impede normal cell division.

It's hard to value chronic oil pollution ecology. Evidence showed that hydrocarbons have mutagenic and carcinogenic effects on human. Crude oil contains polycyclic aromatic hydrocarbons, those are highly toxic to organisms, the toxicity associated with aromatic ring number and extent of alkylation. Toxicity of crude oil in most macromolecular in very high, low molecular also showed strong acute toxicity due to the extremely water soluble and subsequent biological absorption in water. Polycyclic aromatic hydrocarbons gathered in marine organisms, especially in benthic biological tissues and organs, and released their long-term toxicity. When these poisoned marine organisms are ate by marine mammals, fish, shrimp and other food, they will be poisoned, poisoned marine organisms closely related to degree of concentration of oil pollution. But when the concentration do not exceed 1%, the growth of diatoms not only not broken, but also play a catalytic role. With the growth of oil concentration, toxic effects can be demonstrated, the higher concentration of toxic, the more harm to marine ecosystem.

Emulsified oil is particularly serious harm to fish, fish spawn and larvae cause acute effects on fish[8]. Most oils are highly lipophilic, therefore nerve toxic effects on organisms is very obvious. Diesel oil spilled might cause larvae edgy, crazy trips, collision, especially after high concentration of spilled oil, after a period of time, larva swam tends to slow, loss balance flip swire, spastic convulsions, coma paralysis and dead gradually. Fish gills is an important organ of gas exchange, it also has effect of absorption of exogenous pollutants, as a normal physiological process, large amounts of water through gills, poison gathered in gill, caused fish suffocation. Oil is easier gathered in juvenile fish gills, as mucus gill chamber surfaces can not only prevent oil invasion, but also absorb large amounts of oil,

caused gills inflammation and respiratory disorder on older fish. Many fish can survival in latter oil pollution, but probability suffering from gill disease[9,10].

Oil pollutants filled in feather, thereby undermining the insulation performance of feathers, so seabirds easier died of cold, more when seabirds felt oil on feathers, they were panic-stricken, and repeatedly dive attempt to wash away pollutants on feathers. But results were reversed, oil spots on water would be increasingly concentrated in feathers, accelerated death of seabirds. Futhermore, seabirds often swallowed oil and its ramification, it damaged its internal features, including a fatal nervous system. Oil polluted seabirds lost ability to fly, only floated on water, relied on energy stored in body to maintain the rest of their life, accelerated the death of seabirds[10].

3.2 The influence on society by oil pollution

Marine floating oil easily attached to net and other fishing gear, it's difficult to clean, reduced efficiency of fishing gear, increased the cost of fishing. Deeply harm interests of coastal salt chemical plants, desalination plants and other enterprises. These plants are based on seawater as raw materials, it's difficult to use polluted water, caused trouble for production. Offshore oil pollutants near the coast floated with ocean current to coastal beach, brought pollutants to coastal entertainment, seriously affected the development of coastal tourism, impact of coastal city image.

For oil spilled company, the impact cannot be ignored, after oil spills, reputation damaged, while also facing huge compensation, also cause serious bankruptcy [3].

4 Restore of oil pollution

Oil spilled restoration including in physical methods, chemical methods, biological methods and the three mixed.

Physical restoration methods major including, oil clean-up boat cleaning, surrounding oil, and magnetic separation techniques. Physical methods can better removing water surface oil, but for less than 0.3 cm oil slick and emulsified oil is effective. The disadvantage of physical methods is the high cost, not completed oil, and need high operating conditions, but treatment effect only stay in reducing apparent chroma level [11].

Chemical methods including brunt oil method and chemical reagent method. The first method can clean up oil in a short period without complex devices. It is suitable for early stages of oil pollution, more than 3 mm think slick, far from sea area. However, this method is easy to cause air pollution, improper handing easily lead to fire. The second method

mainly including, dispersants, gelling agent, gathering oil agent. Dispersants can reduce surface tension between oil and water, so that formation of emulsions of oil spill on water, oil in water dispersed into small oil droplets, easy to sea chemical reaction, to be able degrade petroleum hydrocarbons degrading microorganisms, eventually converted to carbon dioxide and other water-soluble substances, accelerate the ocean for oil purification process [12].

Gelling agent is a gelling chemicals into the oil block, which gelled after floating on the water surface, recovered by mechanical means. The advantage is low toxicity, ease of recovery, but high cost, complex manufacturing process, promotion is difficult [13]. Gather around the oil through the oil slick or polyethylene film spray oil, or oil to change the surface tension of the film surface, increasing the slick cohesion, preventing the proliferation of slick, so the slick gathered automatically shrink to the smallest area, reducing oil pollution hazards [14]. However, the extensive use of chemicals will produce toxic and harmful substances, can also cause pollution of the sea.

Bioremediation refers in particular microorganisms catalyzing biological degradation of organic pollutants, to repair the contaminated environment or eliminate environmental contaminants in a controlled process or spontaneous. In process of bioremediation mainly by inoculating certain petroleum-degrading bacteria, adding nutrients or surfactants, to provide an electron acceptor and co-metabolic substrates and optimized conditions, it can strengthen the environmental degradation of indigenous microbes spontaneous Oil Pollution process thereof. Bioremediation can be divided into: insitu and exsitu categories. Insitu without water or soil transfer process, the advantage is low cost, but it is difficult to control. Exsitu bioremediation need to be transported in some way from the contaminated site, such transport may increase costs, but facilitate the repair process control [15]. Biodegradation of petroleum hydrocarbons are hydrocarbons from the oil phase transfer to the microbial cells. At present, the microbial cells is generally believed that there are three modes of petroleum hydrocarbon uptake [16] :(1) uptake of the microbial cells were dissolved in the aqueous phase hydrocarbons; (2) microbial cells and thus much larger than the particles in direct contact with a hydrocarbon conduct intake; (3) microbial cells and much smaller than the fake dissolved, to be wrapped in a hydrocarbon solvent or particle effects, and then be ingested.

5 Conclusion

Clean up marine oil pollution is very difficult, physical method usually cost a lot, chemical method may cause secondary pollution, bioremediation is safe, environmentally,

but to explore biological material is an important direction of current research and management.

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溢油污染对海洋生态的影响及修复方法研究

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摘 要：海洋溢油污染持续时间长，在自然常态环境下难以分解，对海洋生物资源及生态环境有巨大的危害。由于污染物随海流流动，影响范围不固定，加之石油烃类化合物难以降解，给海洋溢油污染的治理带来了巨大难题。海洋中逸散石油因其特殊的理化性质、毒性效应，不仅对海洋中的生物造成急性或慢性毒性作用，而且可通过食物链富集和转移，最终可能进入人体，对人类的健康造成严重危害。本文通过溢油污染对海洋生态的影响分析及修复方法的研究，为海洋溢油污染的治理提供理论指导。

关键词：石油污染，海洋生态，修复方法

Effects of carbon sink fisheries ecosystems

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Abstract: Currently, due to the burning of fossil fuels and changes in land use patterns, a lot of CO_2 (carbon dioxide) emissions into the air, the amount of CO_2 in the air is extremely increased. According to the research CO_2 is the main component of greenhouse gases and the main culprit of causing the greenhouse effect. The ocean is a huge repository of carbon, water can dissolve a large amount of CO_2, in the ocean, a large number of plants and planktonic algae absorb CO_2 to produce O_2, It is a very large gathering place (sink). At the same time, CO_2 aggregation in the ocean seawater acidity increases, impact on fishery resources, sources and sinks of CO_2 were discussed in the paper.

Keyword: source and sink, greenhouse gases, ecologicalsystem, fishery resources

1 Fisheries ecosystem status

With the rapid development of the global economy and the sharp increase in population, environmental pollution problems have become increasingly serious, dwindling fisheries resources. Because of eutrophication caused algal blooms, red tide and other problems, serious damage to the ecological balance of the environment, so that a significant reduction in fishery resources, so that fishermen never produced. Red tides and algal blooms are caused by the eutrophication, it will consume a lot of oxygen in the water, causing water to animals (such as fish, shrimp, et al.) hypoxic death. Part of red tide organisms also secrete toxic substances. Different is bloom occurs in fresh water, harm is relatively small: red tide in the sea, the range and harm are large, severe seawater will become a "marine desert."

Overfishing is also an important factor leading to the degradation of fishery resources. Because of China's large population base, more population, leading practitioners in all walks of life very much, say fishermen. The large number of Chinese fishermen, China's

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relatively short coastline, even went to some countries ownership of offshore exclusive economic zone, so relatively few marine resources. In order to obtain the livelihood of fishermen have increased fishing intensity. With the advancement of technology, it applied to a variety of high-tech fishing techniques, fishing intensity is another increasingly important factor in the increase of fishery resources decline.

Severe recession fishery resources, to the people's production and life severely affected, and even endanger human health, bring disease to humans build. Solve or mitigate this problem is quite noteworthy issue. Causes severe recession fishery resources there are many, many people currently working on the sewage treatment methods and efficiency improvements, solid waste disposal methods and efficiency improvements in order to reduce solid and liquid into the rivers, oceans, into the environment, reduce or mitigate pressure pollutants on the environment. In addition to these tangible pollutants have serious harm to the environment, the impact of some of the gas source and sink issues on the environment have particularly serious harm, such as: CO_2, CO, NO_2, SO_2, etc. In addition to long-distance POPs fisheries resources is one of the important hazards. Increased atmospheric CO_2 concentrations enhanced contribution to the greenhouse effect of the largest, accounting for about 50%, is undoubtedly the most important greenhouse gas [1].

The continuing degradation of the water environment is the main factor restricting the sustainable development of fishery resources. Faced with an increasingly acute problem of water environment, the development of fishery resources and ecological conservation science and restoration strategies on the sustainable use of fisheries resources and development has a very important practical significance.

2 The global carbon cycle and carbon sinks

Carbon sources and sinks issue is one that people are most concerned about the issue. The main way of the carbon cycle is: atmospheric CO_2 is absorbed by plants on land and in the sea, then by biological or geological processes and human activities intervene again in the form of CO_2 returns to the atmosphere. CO_2 is a greenhouse gas, it will not only lead to global temperature increases, the formation of the greenhouse effect, is not conducive to the growth of human and animal life, and is the main culprit ocean acidification. Of CO_2 sources and sinks for the protection of fishery resources have great significance. CO_2 source (sink) is: 1. plants, animals, microorganism respiration; 2. the burning of fossil fuels; 3. cement production; 4. land-use change. After three is also the largest source of carbon and human related. CO_2 sinks (source): 1. terrestrial and aquatic

plant photosynthesis; 2. photosynthesis, algae; 3. dissolution of CO_2 in the oceans. According to the latest estimates, the entire C oceans contain about 53 times the atmosphere, the oceans are the planet's largest carbon reservoir [2-4], at present, human CO_2 per year into the atmosphere is absorbed by the ocean about 12.1% 35% of emissions, terrestrial ecosystems absorb approximately 13%, that is to say the ocean and land absorb nearly half of human emissions of CO_2, the other half being released into the atmosphere [5], oceans in mitigating CO_2 greenhouse effect The role of self-evident. CO_2 dissolved into the oceans and marine PH will decline, it is the main culprit ocean acidification. Ocean acidification changes the marine environment affect the growth of aquatic organisms. For example, ocean acidification will affect juvenile olfactory organ, is not conducive to the water to escape predators, juvenile fish cannot grow into adult fish, which leads to species extinction, it will lead to serious food chain collapse. Ocean acidification will affect calcium carbonate shells are shellfish, ocean acidification will shellfish calcium carbonate shell thinning, larval shellfish cannot be generated shell, is rapidly reducing the number of shellfish populations, leading to the eating of meat swimming biological significant reduction into three salmon, reducing catches, reducing the income of the fishermen.

Currently, the global carbon cycle science research are fully operational, it is believed that the efforts for some time, this new discipline will be developed into a set of human and natural mutual penetration, science, ocean carbon sinks research disciplines are crossing each other the global carbon cycle science the most important part. Greenhouse gas effect of oceans in regulating global climate, particularly in terms of the role of CO_2 and other mitigation huge impact on fishery resources CO_2 is huge, so regional as well as global ocean is absorbed (sink) or emission (source) CO_2 is very important.

3 Research progress

3.1 International research trends

Late 19th century people began the study of soil respiration, but as indicators of soil ecosystem, metabolic rate, or measurement of microbial activity. After the late 1960s, research progress on soil CO_2 release accelerates, research deepening, began the study on soil respiration factors, such as: soil temperature, air temperature, soil fertility, latitude changes. 20 in the late 1980s, the global climate issue attention of the world, the source of the problem of CO_2 release attracted widespread attention, research on carbon sources is also increasing.

Improved research methods. The researchers initially only with soda lime or alkali

absorption method to determine the soil breathing, this method of measuring accuracy is low and time-consuming. Infrared analysis with a gas chromatograph appears to solve this problem, it is simple, fast measurement speed and other advantages.

The geographical scope has expanded. Although the study of ecosystem CO_2 flux at present still the United States, Japan, Germany and Australia and other developed countries the majority, their level of study means also is an international leader, but in recent years, along with the fact that global change are countries in the world acceptance and attention, more and more countries and regions began to invest heavily in the country's CO_2 source-sink function to conduct a study in order to gain the initiative in the relevant international negotiations. SCI retrieved from the literature (1998-present), the research on greenhouse gas fluxes have been around the world, from Alaska near the Arctic Circle to the Antarctic tundra soil and snowpack [6, 7], from low altitude plains to the roof of the Qinghai-Tibet Plateau [8, 9], from a wide variety of biological rainforest to the desert green grass-inch hard [10, 11], are related to the research. Of course, because of the huge level of socio-economic and technological development of the world's differences, technical means and the overall level of similar studies in different areas of uneven adoption, through a number of coordinated international research organizations, this situation will gradually improve.

Integrated multi-disciplinary research shows that CO_2 source currency of a complex process is a comprehensive reflection of microorganisms, animals, plants metabolic activity, climate change, marine physical and chemical properties, processes and human activities. In-depth understanding of their flux changes in the law to find the key factors need microbiology, zoology, botany, marine ecology, meteorology, soil science, and atmospheric physics and other disciplines to work together. Currently, large-scale government projects and the implementation of such a trend in some countries, such as the "Amazon River Basin Biosphere - atmosphere interaction of large-scale experiment" by a number of research institutions in many countries, including Brazil, a number of research areas joint international experimental research project.

3.2 Domestic research Overview

Systematic research on soil respiration of natural ecosystems started late, until the twentieth century began to have reports in this regard. By retrieving it found that from 1989 to 1999 of 10 years, China's scientific research papers in terms of soil respiration only 24, followed by Beijing plants and Atmospheric Physics, Chinese Academy of researchers, mainly in Inner Mongolia grassland ecosystems were all kinds a lot of research work. In recent years, with increasing emphasis on global change, and carbon budget situation is

closely related to soil respiration in China's scientific community received extensive attention. For 2000 to date literature search shows that our research papers in soil respiration compared with the previous decade exponential growth (a total of 95), greatly extend the geographical scope of the study, involving the subtropical forests, karst forest, alpine tundra north the original ecosystem, plantation, desert areas, wetlands, grasslands, farmlands and cities, etc. [12-15]. But overall, compared with developed countries of respiration of soil is still in its infancy, and in the research method is relatively backward, lack of long-term, continuous follow-up study, research is not systematic, inadequate exchanges between researchers and so on. With the progress of China's economy and science and technology, this relatively backward situation is gradually improved. For example, China's ongoing large projects nationwide two aspects of the carbon cycle - "China's land and coastal ecosystem carbon balance study" and "Chinese terrestrial ecosystem carbon cycle and its drive mechanism" in big extent, improve the overall level of soil respiration studies. Throughout the last decade of the soil - can be seen between the atmospheric greenhouse gas exchange study aspects of research in this field in farmland and grassland ecosystems to carry out more, get more in-depth study, but in the forest ecosystem is relatively weak, especially In our tropical, sub-tropical regions, there is a small observation points, observation frequency and time span is not enough, lack of process mechanism and other issues, making it difficult to fully and accurately evaluate the contribution of forest ecosystems to global greenhouse gas changes. Major projects CAS Knowledge Innovation Project started in 2001 - "China terrestrial and coastal ecosystems carbon budget research" led the country in the soil - to flourish between the exchange of atmospheric greenhouse gases, and one of the project's sub-topics "China terrestrial ecosystem carbon flux observation and research," 15 stations selected Chinese Ecosystem Research Network 29 field stations among the experimental platform, a unified field sampling and laboratory analysis techniques in line with international standards, to a different country Terrestrial ecosystems in flux three main greenhouse gases were continuous, relatively long-term observational studies, implementation of this project will greatly improve our soil - the level of greenhouse gases in the exchange of research between the atmosphere.

4 Summary

The ocean is an excellent CO_2 repositories, its absorption is approximately 53 times to the amount of land uptake. Nowadays, the effects of CO_2 on fishery resources are not great, but there may be unknown hazards not found, we should actively explore the unknown hazards research and strangle it in the cradle. To prevent unknown hazards and

improve the fishery resources environment, we should do the following.

(a) Through in-depth discussion, study the theory of sources and sinks, a clear understanding of carbon sources and sinks, targeted to govern. From the source control their generation, reducing the "source", increasing the uptake, and increasing "sinks" to increase the rate of absorption of the degradation of pollutants. Setting fishing areas and seasons, is the ocean of time and space to restore ecological stability. Manual intervention by accelerating can increase the ecological recovery speed.

(b) CO_2 is absorbed by ocean acidification will cause. CO_2 is dissolved in water to form a weak acid - carbonic acid, carbonic acid is formed causes water acidification, the impact on the marine environment, the impact of fish and shellfish to survive and multiply. Due to the vast area of ocean, and carbonic acid is a weak acid, so the impact on the marine environment is not too much water inside, also can empty range. But people cannot relax our vigilance therefore, some hidden impact is unclear, studies need to be strengthened, to take preventive measures.

(c) CO_2 is absorbed by seawater, and it can ease the greenhouse effect, and reducing atmospheric CO_2 content. Oceans absorb large amounts of carbon in the atmosphere is 53 times the terrestrial uptake, greatly easing the CO_2 greenhouse effect, carbon excellent repository.

(d) We should strengthen research on CO_2 sources and sinks, CO_2 in the sea now is not great, still within manageable, impact on fishery resources is not great, we should strengthen the research found that carbon undiscovered source, observing its impact on fishery resources, minimize their harm.

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碳源汇对渔业生态系统的影响

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摘要：目前，由于化石燃料的燃烧，与土地利用方式的改变，人们向空气中排放了大量的 CO_2，使空气中的 CO_2 量极具增加。据研究：CO_2 是温室气体的主要组成部分，地造成温室效应的主要元凶。海洋是碳的一个巨大储存库，海水能够溶解大量的 CO_2，海洋中大量的植物和浮游藻类吸收 CO_2 产生 O_2，是 CO_2 非常大的聚集地（汇）。与此同时 CO_2 在海洋中的汇聚使海水酸度增大对渔业资源造成影响，本文主要对 CO_2 的源汇进行分析讨论。

关键词：源汇；温室气体；生态系统；渔业资源

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